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Chadwick Lectures

SESSION - 1907-08

BY

W. D. SCOTT-MONCRIEFF

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CONTENTS

LECTURE I

Historical and Introductory—Insanitary Condition of England Previous to First Public Health Act—Efforts of the Pioneers—Necessity for Removing Filth from the Neighbourhood of Dwellings—Enumeration of Acts of Parliament—Reports of Royal and Other Commissions—Accounts of Progress—Mr. Adrian's Evidence—Dominant Features—Land Regarded as a Universal Method of Disposal—Disappointed Hopes—Chemical Processes—Electrical Treatment—The Coming of Natural Methods—Pasteur, Warington and Lawes, Mueller, Mouras—Ashtead Experiments—Importance of High Nitrification—Failure of Royal Commission on Sewage Disposal to Place the Subject on a Scientific Footing—Retrospect ... 9–25

LECTURE II

The Functions of the Physician, Chemist, Bacteriologist and Engineer in Sanitary Progress—"Works"—Selecting Sites—Removing Organic Wastes—Providing Immunity from Foul Gases—Devising Methods for the Purification of Sewage—Primitive Methods of Disposal—The Price Paid for Sanitation in England More than Poor Countries can Afford—The Water-carriage System — Serious Limitations — Domestic Sanitation—Principles Involved—State of in 1881—Disconnection and Ventilation—Sewers—Proper Construction—Rapid Development—Waterlogged Soils—Sewer Ventilation—Unsatisfactory Position—The Case of Bristol—Health Statistics—Hydro-mechanical System of Shone & Ault—Experience at Leicester—First Cost and Annual Cost 26–43

LECTURE III

Sewage Disposal—Purification and Manurial Value Combined—Disposal in the Sea, Lakes and Rivers—The Lake of Geneva and the Rhone—American Rivers—Land Treatment—Limited to Suitable Soils—Berlin Sewage Farm Contrasted with Birmingham Figures and Statistics—Dr. Barwise on Soils—Royal Commission on Sewage Disposal: Their Officers' Reports on Land Treatment—Practical Management of Sewage Farms—Straining and Settling—Detritus Chambers—Chemical Deposition and Hydrolysis—Unsatisfactory Methods of Taking Samples—Septic Action and Sludge—Upward Filtration through Stones — Single and Double Contact—Superior Results from Percolating Filters—Value of Sludge—Incoherence in Practice—Genesis of the Contact Bed—Absence of a Scientific Basis of any Kind 44–60

LECTURE IV

What the Engineer Ought to Know—Unreasonable Demands—Failure of Chemists to Supply Definite Data—Chemistry and Bacteriology of Sewage Treatment Stated in a Popular Form—Constituents of Sewage—Complexity of Processes Involved—Organic Nitrogen the Most Important

CONTENTS (*continued*)

Feature—Oxidised and Unoxidised Nitrogen—Failure to Arrive at Common Methods of Analysis — Misleading Estimations — Offensive Odours — Difficulty of Dealing With—Bacterial Treatment—Explanation of Terms—Putrefactive and Oxidising Changes—Information Necessary to Designing Installations—Aëration and Other Factors—Procedure after Information has been Obtained—Construction of a Single Unit Before Going Further—Attitude of Local Government Board—The Use of a Testing Apparatus—Importance of Accuracy of Distribution—Different Kinds of Distributors—Objections to the Spraying of Sewage into the Atmosphere—Residuary Substances — Experience at Staines — Recent Contributions from the Massachusetts Board of Health—Some Recent Experiments in England—Conclusion 61–79

INTRODUCTION

CHADWICK LECTURES

The Chadwick Lectures in the University of London were established in 1907 for a period of five years, the endowment being derived from the funds of the Trust created by the Will of Sir Edwin Chadwick, K.C.B., in 1895. Two short courses of lectures are to be delivered each year at the University on subjects relating to Sanitary Science, with special reference to recent advances in Hygiene and Municipal Engineering.

Sir Edwin Chadwick, who was born in 1800, devoted the greater part of his life to the improvement of sanitation and to social problems connected therewith. He was at first Assistant Commissioner, and then Chief Commissioner, of the Poor Law Commission in 1832, and was a member of several Royal and other Commissions—*e.g.*, those on the condition of Factory Children (1833), on the Police (1838), on Sanitation (1839, 1844), and on the Health of London (1847). His interest in these subjects was doubtless awakened by the distressing social conditions which followed the industrial revolution; as a young man he determined to make sanitary reform the work of his life, and he thenceforth devoted himself unsparingly to the attempt to improve the moral and physical health of the country.

Chadwick was not a student or graduate of the University of London, but he was intimate with some of the founders and early promoters of the University. In 1867 he was actually a candidate at the first election of a Member of Parliament for the University, but was defeated by Mr. Robert Lowe, afterwards Viscount Sherbrooke.

INTRODUCTION *(continued)*

Among Chadwick's friends was Jeremy Bentham, who, perhaps, exercised the most marked influence on his mind and character. Bentham bequeathed to him a considerable number of his books; and these have now passed into the possession of the University, having been deposited with many other of Bentham's manuscripts and papers in the University College Library.

Chadwick died in 1890, and left by his will and codicil certain investments producing an annual income of about £885 in trust for purposes connected with the promotion of the study of Sanitary Science, including the establishment of Professorships in Sanitary Science in its medical and engineering aspects, and the provision of lectures on this subject. The Trust is at present regulated by a scheme, confirmed by order of Mr. Justice Chitty, dated the 23rd day of February, 1895. In 1897 the Trustees granted a capital sum of money for the equipment of a new Department of Municipal Engineering at University College, London, and an annual grant for the salaries of teachers of Hygiene and Municipal Engineering and for the equipment necessary in connection with their work. In 1899 a Chadwick Scholarship in Municipal Engineering and Hygiene was also established at University College. Since the incorporation of University College in the University the Chadwick Trustees[*] have made an annual grant to the University which is devoted to the payment of the emoluments of the Chadwick Professor of Hygiene in the University and to the emoluments of the Chadwick Scholar.

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[*] The names of the present Chadwick Trustees are as follows:—
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The publication of the present volume, containing the lectures on "The Engineering Aspect of Recent Advances in Connection with Sewering," delivered at the University in May, 1908, by Mr. W. D. Scott-Moncrieff as Chadwick Lecturer, has been rendered possible by a special grant from the Chadwick Trust. It has not been easy in the past for such practical or technical subjects to find their proper place among University studies. That they are of the utmost importance none will now deny; and that they may best be studied in their more advanced aspects in a modern University and in an atmosphere of learning and research is generally accepted.

It will be seen from the foregoing brief account that Sanitary Science as a University subject owes much to the personal effort and wise foresight of Sir Edwin Chadwick.

HENRY A. MIERS,
Principal.

University of London.
February, 1909.

LECTURE I

Of the period when first the Engineer, in the modern acceptance of the term, was associated with the work of sanitation it is difficult to speak with any certainty. Dr. Halbherr, the Director of the Italian Archæological Mission to Crete, writes of the recent discoveries in the Minean palaces as quite "al Inglese" in the matter of hygienic appliances. Not the least interesting portion of the buildings is the elaborate system of drainage with lavatories and traps. The main drain of the palace at Knosos is 3 ft. in height and is coated with cement, while terra-cotta pipes have been found running beneath the floor with small and large ends corresponding to the socket joints of the latest sanitary catalogues.

It is indeed difficult to realise that the engineers who produced these arrangements and appliances lived at a period so remote that the civilisation to which they contributed only survived as a faint tradition at the time of Homer, and that these traps and lavatories were being specified and fixed before Moses had begun to promulgate the sanitary laws which we find written in the Book of Deuteronomy.

Compared with such antiquity, the great sewers, aqueducts and public baths of the Romans appear almost recent in the vista of these innumerable years. Ages of advancing civilisation must have preceded the work of these early engineers, and yet the very name of the race to which they belonged has apparently been lost for ever. Such obliteration and oblivion never came to Rome, but the downfall of the Empire seems to have brought an end to all sanitary progress, and the great lessons to be gathered from her achievements were first neglected and then utterly forgotten.

A supreme indifference to hygienic surroundings seems to have been characteristic of every European nation from the time of the disappearance of the Latin supremacy until the work of sanitation was begun in England about sixty years ago. It is doubtful if there was a single town in Great Britain at the beginning of last century, or even at the time when Sir Edwin Chadwick first began his work as a sanitarian, that could compare, in the matter of hygiene, with a second-rate city at the time of the Roman occupation. The urban population of this country and of Europe when men still living were born, passed their lives amid sanitary conditions of the most primitive kind, and there were few houses in England so healthy to live in, or so supplied with the luxury of cleanliness, as the villa of a Centurion at the time of Hadrian or Agricola.

It would be easy to draw a somewhat lurid picture of the sanitary condition of Great Britain about the middle of last century from the materials to be found in the reports of various Commissions, and from other sources as well, but it is enough to point out that the towns throughout the entire country were unprovided with sewers, to understand how far from hygienic the surroundings were amid which our urban populations were obliged to live.

It is to Sir Edwin Chadwick and his associates that we are indebted for the proud position which this country now holds in the van of sanitary progress.

In the words of Mr. Winslow and Mr. Phelps, of the Massachusetts Institute of Technology, "the wonderful administrative work of the British sanitarians effected the greatest sanitary progress which has probably ever been known." The midden system and the pail system rapidly gave way to the water-carriage system. Until 1815 the discharge of any waste but kitchen slops into the drains of London was prohibited by law, and the same regulations existed in Paris until 1880. In 1847, three years after the Report of the Health of Towns Commission, it was made obligatory to discharge all sewage into these drains.

One of the first changes brought about by the efforts of the pioneers was effected by the passing of the Public Health Act of 1848, which included a scheme of local government and control for the improvement of the sanitary condition of towns and populous places under the supervision of a temporary body, the General Board of Health.

The second change of the administrative machinery due to their labours occurred in the passing of the Local Government

Act on the 2nd of August, 1858, and both of these statutes had their inception from what has been spoken of as the epoch-making Report of the Health of Towns Commission of Great Britain in 1844, which revealed "such an astonishing amount of decomposing organic matter and filth of all kinds in the cities that it aroused British sanitarians to a strong movement for the amelioration of these conditions and led to the filth theory of disease."

Without entering into details, the mere enumeration of the Acts of Parliament and the reports of Royal Commissions shows that the expert and administrative labour involved in the evolution of modern sanitation in England has been enormous. The following is a list of the Commissions and their reports :—

1843. Health of Towns Commission.
1844. First Report of Towns Commission.
1845. Second and Final Report of Towns Commission.
1857. Royal Commission appointed to inquire as to the best means of distributing the sewage of towns.
1858. Preliminary Report of Sewage of Towns Commission.
1861. Second Report of Sewage of Towns Commission.
1864. Report of House of Commons' Commission on Utilisation of Sewage.
1865. Royal Commission appointed to inquire as to the best means of preventing the pollution of rivers. (Rivers Pollution Commission.)
Third Report of Sewage of Towns Commission.
1868. Second Rivers Pollution Commission appointed.
1869. Royal Commission appointed to inquire into and report upon the operation of Sanitary Laws outside the Metropolis.
1870. First and Second Report of Rivers Pollution Commission.
1871. Third Report of Rivers Pollution Commission.
1872. Fourth and Fifth Report of Rivers Pollution Commission.
1874. Sixth and Final Report of Rivers Pollution Commission.
1882. Metropolitan Sewage Commission appointed.
1884. First Report of Metropolitan Sewage Commission.

1885. Second and Final Report of Metropolitan Sewage Commission.
1898. Commission appointed to inquire and report what methods of treating and disposing of sewage may properly be adopted.
1901. Interim Report of Royal Commission.
1902. Second Report: 1903, Third Report: 1904, &c., Fourth Report of Royal Commission.

In referring to the Acts of Parliament which resulted from these investigations it should be pointed out that, previous to the appointment of the Health of Towns Commission in 1843, the sewers in use in this country were originally constructed by Commissioners of Sewers primarily for the disposal of surface water only, under the Statute 23, Henry VIII., c. 5, and according to the estimate made in 1843 these commissions acted for about eighty districts outside the Metropolis. The sewers were, in fact, highway drains, and very serious nuisance was reported owing to their being used for the discharge of sewage.

The Commissioners of 1843 reported that "the exhalations and offensive effluvia from the non-cleansing of such drains producing fevers and other diseases added to the miseries of the poorer inhabitants, and to the expenses both of the parish and individuals."

The legislation which followed from the reports of the Royal and other Commissions included the following Acts of Parliament:—

1848. The first Public Health Act.
1858. The Local Government Act, 1858.
1861. The Local Government Amendment Act.
1865. The Sewage Utilisation Act.
1866. The Sanitary Act, amending the Sewage Utilisation Act.
1867. Another Sewage Utilisation Act.
1868. An Act to amend the Sanitary Act of 1866.
1869. Sanitary Loans Act.
1870. The Sanitary Act, 1870.
1871. The Local Government Board Act, 1871.
1872. The Public Health Act, 1872.
1875. The Public Health Act, 1875.

1876. The Rivers Pollution Prevention Act.
1890. The Public Health Act Amendment Act, 1890.
1893. The Rivers Pollution Prevention Act, 1893.

It would be altogether beyond the scope of these lectures to go into any detail with regard to the inception, evolution and administration of these fifteen statutes or to discuss in what way they have met or disappointed the expectations of their framers, but it is well to show how much they have been codified by quoting a statement made by Mr. H. D. Adrian in his masterly evidence given before the Royal Sewage Commission of 1898, in which he remarks: "It may be said that for all practical purposes the general law relating to sewage disposal in England and Wales is to be found in the Public Health Act of 1875, supplemented by the Rivers Pollution Prevention Acts." At the period of the passing of the first Health Act of 1848, a few isolated cases existed in which there was something approaching to modern methods of sewage disposal, and these are the more interesting because they embodied, in a somewhat rudimentary form, the system strongly advocated by Sir Edwin Chadwick which provided for the removal of the sewage in sewers to a distance from all centres of population.

The oldest instance of this was the well-known case of the Craigentinny Meadows near Edinburgh, which appear to have been used for sewage irrigation towards the end of the eighteenth century. In his report to the Poor Law Commissioners in 1842, Sir Edwin Chadwick described the system, but, whether on account of the objections of a colleague or because of the opposition of the Government on the ground of danger to the health of the occupants of Holyrood Palace, his opinions were by no means favourable to the system of disposal upon land as then carried out, though he still advocated the construction of sewers as an absolute necessity. He gave his opinion that if the contents of the cesspits were carried by means of adequate supplies of water and thence in covered instead of open sewers to the land at proper distances, when the contents might be distributed as manure by irrigation, this would be the best method then apparently practical. It is probable that the details of the sewage arrangements in Edinburgh, and the methods of disposing of it, were so objectionable that even an advocate of the system when properly carried out might object to the suggestion that they in particular should be referred to favourably as applicable to other places or desirable in themselves. It is indeed difficult to think of any other system than the one recommended as being available at the time, and the only question to be decided was as to the best methods of carrying it out. This one had at least the advantage of providing a more sanitary means for the removal of filth than first collecting it in cesspits and then having it carted away to a distance that was necessarily limited by the cost of its conveyance.

Three years after the appearance of Sir Edwin Chadwick's report the Towns Improvement Clauses Act was passed in 1847. This statute recognised two methods of sewage disposal —first, the getting rid of it without any attempt at making it a source of profit, and second, the methods of profitable disposal. Under the first heading the local authority might cause their sewers to empty themselves into the sea or any public river, or, under the second method, the authority might cause the refuse from the sewers to be conveyed by a proper channel to the most convenient site for its collection and sale for agricultural or other purposes as might be deemed most expedient, but so that the same should in no case become a nuisance.

In his evidence before the Royal Commission of 1898 Mr. Adrian makes an important observation upon the significance of the term "Public River," and suggests that the words may be explained by a reference to Lord Hale's treatise, *De Jure Maris*, as meaning a river which is *publici juris* and a common highway for men and goods—a navigable stream which may be fresh or salt, and which may flow or re-flow or not. This Act of 1847 may be regarded as a clear index as to the state of professional and public opinion upon the subject of sewage disposal at the time, and the changes which have occurred since it was placed on the Statute Book have been directly due to the urban populations continually adding to the pollution of the streams into which they discharge their sewage. This is borne out by the first Public Health Act of 1848, where the distinction between the profitable and unprofitable disposal of sewage is recognised and where there is a significant omission of rivers as an allowable means of getting rid of it.

Under sec. 145 of that statute nothing in the Act was to be construed to authorise the local authority, without previous consent in writing, to use, injure, or interfere with any watercourse or stream in which the owners of certain property or the proprietors of canals or navigation might be interested.

A notable commentary upon the advancing notions of the time is to be found in a report by the General Board of Health in 1854, when their term of office was expiring. There is an Appendix of "conclusions obtained on application of sewer water and town manures to agricultural production," in which they expressed the opinion "that it was far less injurious to the public health to have the refuse of towns in water in the nearest river than underneath or amidst dwellings." But in view of the germ theory of a large number of diseases the most dangerous conditions that have ever existed must be found in cases where septic sewage, swarming with the organisms of putrefaction, is now being sprayed into the atmosphere in the close vicinity of large and densely populated cities.

In another part of their Appendix the Board of Health dealt with the question of sewage disposal, and pointed out that "by shedding from hose, after the method of distribution of garden watering, the exposure to evaporation is so far reduced in amount and time and the absorption by the land so immediate that it is inappreciable in its effect upon the persons exposed to it." What the Board of Health would have thought of appliances for spraying millions of gallons of septic sewage into the atmosphere in a gale of wind it is not difficult to imagine.

This Report of 1845 was made three years before what Mr. Adrian regards as the first of three distinctive periods in the evolution of the statute law on the subject of sewage disposal. He describes the dominant opinion of the years following 1842 up to 1857 as embodied in the conclusions—first, that it is of primary importance to secure the prompt removal of sewage from the neighbourhood of dwellings; second, that the use of a river outfall is preferable to the retention of sewage near dwellings; third, that in consequence of doubts as to the effects upon the public health of the irrigation of large surfaces with liquid sewage, the best system of disposal is by underground pipes for subsequent distribution by hose or jets.

The dominant feature of the second period, which he places between the years 1858 and 1870, was still the pressing need of improved sewering and the conveyance of sewage from the neighbourhood of dwellings, accompanied by the abandonment of the fear of injury to health from the irrigation of land by sewage, and a growing belief that profitable utilisation on land would solve the problem of river pollution.

Experience has now shown that the hopes of profit from sewage farming can never be realised except under more or less ideal conditions which seldom exist, but in 1862 we find Sir Robert Rawlinson putting the question of profit, and even of river pollution, as subsidiary to the all-important requirement of removing sewage from the vicinity of houses. He said: "There is at present a great outcry against the pollution of rivers by sewage and the killing of fish. The question may be asked whether it is better to pollute rivers or pollute towns and houses, to kill fish or to kill men. I do not advocate the pollution of rivers, but the application of sewage to land for agricultural use. If it will not pay as a commercial speculation, make it compulsory and pay the cost by rates. By far the most costly condition in any community is filth in cesspools beneath houses or on the surface around human dwellings." The pioneers were upon safe ground when they insisted on the removal of sewage by means of well-constructed sewers with ample supplies of water, but both they and many of their successors have failed to make stiff clay do the duty of sand or gravel, and their failure has proved to be an expensive one to the unfortunate ratepayers who have had their money thrown away in attempting to achieve the impossible.

During the years referred to, the profitable utilisation of sewage and its derivatives upon land became the subject of endless experiment. The schemes of inventors were taken up by companies often working in ignorance of the conditions essential to the attainment of success, and money was freely invested on the supposition that raw sewage could be dealt with at a profit by enriching the land upon every kind of soil, at all seasons, and under every condition of climate. In addition to these expectations with regard to profit, the sewage farm was also looked upon as a solution of the problem of purification.

If any land was proved to be unfit for irrigation at certain seasons, then satisfactory results could surely be obtained by the simple expedient of an elaborate system of drainage with intermittent filtration. If this was a failure the sewage could be treated by chemicals so as to yield a profit all the same, if by irrigation so much the better, but if not by the production of a saleable manure, for which the demand must in the nature of things be as unlimited as the need for food. Whatever form the problem took there were always enthusiasts who could prove a profit.

When occasional success was achieved by reason of exceptionally favourable conditions it seldom led to a careful examination as to how and why it was obtained. The difference between one situation and another was often ignored until widely different results proved the inadequacy of the data upon which conclusions had been drawn and money wasted.

Certainly the doubts that had been raised by the old Board of Health as to the possibly bad effects of sewage irrigation upon the public health never seemed to trouble its advocates in any way, but for altogether different reasons the chemical processes came more and more into favour, and endless efforts were made to discover a solution of the problem by the researches of the laboratory.

In his presidential address to the Association of Sewage Works Managers in 1905, Mr. Baldwin Latham said: "There is hardly a single earthy salt or metallic compound which has not been proposed at some time or other for the purpose of the treatment of sewage," and, in giving a history of the subject, he notes as many as twenty-eight different processes, every one of which had a considerable notoriety at the time it was proposed, and all of them involving numerous and expensive experiments. No fewer than 417 patents were issued between 1856 and 1876 for the chemical treatment of sewage.

Perhaps one of the most rational proposals, in so far as it aimed at the production of an easily handled and saleable manure, is still in evidence and can be seen in operation at Kingston-on-Thames. I make special reference to this because it attempts to deal with what has hitherto proved to be a weak point in all chemical processes where the problems of profit and purification are combined. It is known as the A. B. C. process. It recognises the importance of the product being placed on the market in a convenient form, and this is arrived at by drying the sludge. If it be urged that the method is not practicable in the case of communities with a daily discharge of millions of gallons of sewage, the answer is that the scale on which it is conducted can never be too great so long as every ton of the product can be sold at a profit, and so long as the demand remains unlimited. All things being equal, and if the process had no defect, the reply would be a good one. Unfortunately it shares the defect of all chemical processes that have hitherto been discovered, because even in the clearest effluents the matters in solution are in a form that is universally liable to a secondary putrefaction and are not capable of conversion to their innocuous mineral equivalents at a cost that is not prohibitive, even indeed if they can be converted at all, by a purely chemical process of any kind.

It is difficult to imagine any greater disappointment than, after the economical production of a clear and odourless effluent, to find it followed by a secondary putrefactive change that so far has defied the efforts of the chemist to get rid of at a reasonable cost. This point has been clearly brought out in the evidence of the most eminent chemists who have devoted their efforts to the discovery of a remedy, and the late Sir Edward Frankland put the case clearly when he stated that it was not the matters in suspension but those in solution that were the real crux of the problem. Until this difficulty has been overcome by some inexpensive remedy all the chemical processes may be regarded as more or less of a failure.

It was not until the simpler methods of Nature had been discovered and applied that the solution of the problem came fully into sight. The sanguine expectations of the advocates of land treatment and the hopes that a chemical remedy would be discovered with the advancing knowledge of the times led to both solutions of the problem being almost equally in favour, and while neither Royal Commissions nor Government experts appear to have made any contributions of importance, the restrictive legislation which resulted from their recommendations and advice was a constant stimulus to the efforts of municipalities to purify their sewage, while engineers and chemists found a rich harvest of remuneration in the growing demand for their services.

Mr. Baldwin Latham, in the address already referred to, states that when Mr. Arthur Aikin was asked what was the best agent to use for clarifying sewage he answered milk of lime. This was in 1845, following the introduction of the Clark process for softening water in 1841. In 1853 the lime process was introduced at Croydon, but with no satisfactory results, as it was found that an effluent produced in this way is often more destructive to fish than the crude sewage itself. In 1859 Messrs. Hoffman and Frankland recommended the persalts of iron as the best precipitant. It is enough to mention magnesia, magnesian limestone, phosphates, including the superphosphate of magnesia and of alumina dissolved in sulphuric acid, dicalcic phosphate and others, all of which were failures on account of the expense and the small return obtained by the sale of the manure. In 1860 an electrical process was carried out by Mr. Chisholm at Watford, and in 1887 on London sewage by Mr. Webster. The latter introduced iron plates used as electrodes, the positive pole liberating the chlorine and oxygen so as to deodorise the sewage, while the iron salts formed assisted in the purification. This was followed by the Hermite process, in which electricity was employed so as to obtain from sea water a liquid in which there was 0·5 gramme of available chlorine per litre. Success with such processes has been rendered altogether impossible, so far as they are in opposition to the now accepted views about bacterial action, which it is their special function to inhibit. A broad distinction, however, exists between a sterilised and a sterilising effluent coming from either a chemically treated or a bacterial tank, and in certain cases the only way of surmounting exceptional difficulties in the treatment of a particular effluent might be by passing it through an actively nitrifying filter after the bacteria of the incoming liquid have been destroyed.

It was inevitable that in the midst of so many schemes some of them should be lacking in a scientific basis of any kind, and should acquire a notoriety on the strength of claims that were grossly exaggerated.

The general outcome of these efforts led to the employment of chemists and engineers in land and chemical treatment all over the country. The duty of the engineer was to adapt unsuitable land to the purification of sewage by means of intermittent filtration and other devices, while the chemist was called in to decide the adequacy of the results obtained. Although few, if any, of the conditions were ever identical, it was always easy to argue from one case to the other, and yet, when it was shown that as much as 100,000 gallons per acre per day could be successfully treated at one place, it by no means followed that even half that quantity could be disposed of in another less favourably situated.

As a matter of fact the quantities varied in practice from about 14,000 gallons to less than 3,000 gallons per acre per day, and in this respect, as in many other phases of the problem, the absence of a common basis of any kind has always been one of its most prominent characteristics. When chemicals were used a certain number of appliances became necessary. These included screening arrangements to keep back the larger bodies that are conveyed in the sewage to the outfalls, and they have generally been devised so as to take advantage of the flow to give the necessary movements to the mechanism employed. In addition to the screening appliances, mixing machines were employed for dosing the sewage with measured quantities of chemicals, and, in order to reduce the volume of sludge, presses were introduced which were capable of removing about 30 out of the 80 or 90 per cent. of the water contained in it. Where sufficient land is available at a reasonable distance from dwellings, trenching the sludge and allowing it to dry, partly by percolation and partly by evaporation, has been found to be satisfactory. The cost of pressing, being about 2s. 6d. per ton, has always been an important factor in deciding upon the method to be employed. With the recent advances that have been made in bacterial processes many of the mixing machines and sludge presses have become derelict and altogether abandoned, but until the year 1892 there was nothing on the horizon, beyond a series of short articles by Mr. Adeney in the *Health Record*, to indicate any radical change in a practical form.

For good or evil the water-carriage system had been adopted, and it apparently lay with the chemist, the farmer, and the engineer to find some way out of the network of disappointed hopes and the endless confusion arising from the use of misleading data, which has been the characteristic of the sewage problem ever since primitive methods of disposal were proved to be inadequate. The collaboration of the bacteriologist was never thought of. Down to the year 1892 a few references had been made to the work done by natural processes in the conversion of organic matter into its inorganic elements, but these had not materialised in any practical suggestions as to how they should be applied. Warington and Lawes had been at work upon the phenomena of plant growth in its relation to the chemical changes which occur in the soil and the nitrifying changes which are essential to the conversion of manure to a condition in which it is assimilated by vegetation. Warington, in a paper contributed to the Society of Arts in 1882, clearly suggested the idea of a bacterial filter when he said "it would be possible to construct a filter-bed having a greater oxidising power than would be possessed by an ordinary soil or subsoil." Pasteur had gone far to explain the facts of fermentation and shown that putrefaction was the work of organisms whose life processes, when arrested, led to a suspension of the changes themselves. The Massachusetts State Board of Health had already undertaken a series of experiments which carried the investigations beyond the natural conditions of cultivated soil, and showed how what occurred in downward filtration was also due to the work of microscopic organisms. It is interesting to note, however, that the practical work of sewage purification went on without any attention being paid to the possibilities suggested by these investigations, and although "it is clear, while in the early eighties the theory of sewage oxidation was understood by French and German investigators, the practice of intermittent filtration had already been worked empirically by Frankland and Bailey-Denton in England" (Mass. Reports), and it is of interest to observe that all the investigations referred to were connected only with the phenomena of oxidation and nitrification, and that another phase of the problem was altogether disregarded.

In the conversion of organic wastes Nature works in two stages that are widely dissimilar. It had already been shown by Pasteur that they are carried on by organisms so widely different in kind that no two groups have a dividing line—that is, wider in itself or more significant in its operation. It was quite to be expected that the characteristic of what are known as the anaërobic group, being associated with the work of putrefaction, should have repelled any attempt to employ them in the work of purification, but when it was discovered that they performed an important part and prepared the sewage for the work of the nitrifying organisms a new light was thrown on their importance. It was then found that about the year 1865 Alexander Mueller had described the purification of sewage as a process of digestion and mineralisation, and had taken out a patent in 1878 for the purification of sewage by the scientific cultivation of yeast-like organisms. We have here an early suggestion in the words " digestion and mineralisation " of the two natural stages already spoken of, but there is no indication that Mueller's proposals had ever made a mark of any kind. The first announcement in England of a deliberate effort to utilise the organisms of putrefaction under controlled and regulated conditions appeared in a London evening paper on the 24th of September, 1892, and described certain experiments which had been carried out upon the sewage from a country house at Ashtead, in Surrey. At the same time the reports of the Massachusetts Board of Health upon their filtration experiments were beginning to bear fruit and led to the experiments at Barking, which had their outcome in the well-known contact bed.

Mueller seems to have had a more or less scientific perception of how Nature should be approached, but before the publication of his first suggestions Mouras, in 1860, introduced the *vidange automatique*, which laid claim to doing away with the necessity even for periodic removal of the solids.

About three years after the first Ashtead experiments, others were commenced by Mr. Cameron at Exeter that developed into what is now widely known as the Septic Tank, the principle of which had been anticipated by Mouras, and then there came a combination of the Exeter Tank and the Barking Contact Bed, which was extensively advertised and has been more or less in vogue ever since.

In 1897 experiments were made with a view to embodying the theory that the sequence of changes occurring in the process of liquefaction and purification by micro-organisms was the work of naturally-selected groups, each dealing with a differentiated food supply as the work proceeded, and this was carried out by superimposing filtering trays with air spaces between. The results obtained were far in advance of anything that has been obtained by any other process, and the purification was extraordinarily high. The upshot of these experiments was that for the first time a liquid was obtained by a purely natural process from ordinary domestic sewage which in itself provided all the elements of a practically perfect plant food, and it is unfortunate that the impetus given to other less perfect processes by their advocates has diverted attention from the conditions which gave incomparably better results.

It has since been shown that furnishing the organisms that work under anaërobic conditions with a nidus for their development by means of the stones placed in "cultivation tanks" not only produces a liquid in which the organic substances are thrown into an unstable form readily susceptible to further purification, but is also associated with a conservation of the nitrogen which, in the septic tank and contact bed, disappears in the process and is not recovered in the effluents to anything like the same extent. The mere fact of having as much as 9 parts of nitric nitrogen per 100,000 in the effluent from ordinary sewage is of immense importance, and showed that the problem of purification and conservation of nitrogen in a mineral form could be combined in a purely natural process. Everyone who has written text-books on the subject of biolysis recognises the vast difference between the merits of an effluent containing 2 or 3 parts per 100,000 of nitric nitrogen and another that contains 9 parts, but no one seems to have thought it worth while to inquire as to the exact nature of the conditions which led to these remarkable results.

Even now it is not always recognised that the high nitrification is due to the separation of the different groups of organisms as well as to the large amount of air available between the spaces of the trays.

Yet these are the questions that ought to have had an answer long ago. It has already been observed that few practical contributions of any importance have been forthcoming from official sources, but while it is impossible to give anything like an exhaustive history of the subject within the narrow limits of four lectures, they would not be complete without making some reference to the most important event, from an official point of view, which has occurred since the second and final report of the Metropolitan Sewage Commission in 1885. I refer to the Royal Commission appointed in 1898 to inquire and report : I. (1) What method or methods of treating and disposing of sewage (including any liquid from any factory or manufacturing process) may properly be adopted, consistently with due regard for the requirements of the existing law, for the protection of public health, and for the economical and efficient discharge of the duties of local authorities ; and (2) if more than one method may be adopted, by what rules, in relation to the nature or volume of sewage, or the population to be served, or other varying circumstances or requirements, should the particular method of treatment and disposal to be adopted be determined ; and II. To make any recommendations which may be deemed desirable with reference to the treatment and disposal of sewage.

It would not be becoming in me to attempt any elaborate criticism of the work of this Commission, even if there were time enough at my disposal to do so. The sewage problem has so many aspects, and has been so seriously complicated by the difficulties arising from trade wastes and the disposal of storm water, not to speak of the scarcity of suitable land, that the labours entailed on the Commission were of the most onerous kind, but at the same time it is only right to observe that they have failed to make an effort, so far as I know, to arrive at any sort of basis which can be spoken of as even remotely scientific. This observation is not so disparaging to the work of the Commission as it appears, because it is only another way of stating that they have never had a common standard of measurement, without which it is impossible to have a scientific basis of any kind. They have at any rate been most fortunate in having found a capable historian, in the person of Mr. Martin, whose masterly *résumé* of their work is a model of its kind. Every student of the subject will find in this book not only a condensed reproduction of the work of the Commission in a form that is eminently readable, but a reserved and cautious element of observation which is seldom at fault. Their labours have been permanently rescued by Mr. Martin from the recesses of a Blue Book, and presented in a form that will always be available, without the necessity for wading through more or less irrelevant details.

At the present moment the Commission propose that there should be a central authority with full powers for dealing with the question of river pollution and water supply, and that they should hand over to them the results of their labours. I shall take the opportunity of again referring to this proposal in a future lecture, when dealing with the incoherent position of the whole subject, but meantime I cannot do better than refer those who are interested to the admirable text-books by Dr. Rideal and Dr. Barwise, and I know of no better history of the subject of sewage disposal than that to be found in the contribution from the Massachusetts Institute of Technology, written by C.-E. A. Winslow and Earle B. Phelps.

In looking back upon what has been already accomplished in England it is well to remember that when Sir Edwin Chadwick and his colleagues began their work of sanitary reform there were practically no sewers in this country at all.

If the indifference to hygienic conditions had continued, as it must have done had no one undertaken the work, it is easy to realise the great blank that would have now existed in matters affecting the health and welfare of the entire community.

It was by concentrating the attention of experts upon the pressing sanitary necessities of the time that conceptions began to be formed which have developed into what may be spoken of as the science of cleanliness: and this has had an outcome that no one dreamed of at the time when the first labours of the pioneers were undertaken. Before the era of cleanliness had begun, and at a quite recent period, many surgical operations were performed at the risk of almost certain death. If these can now be performed with something approaching to a certainty of success, it is to the insight, the philanthropy, and the energy of a group of pioneers, among whom Sir Edwin Chadwick held a most distinguished place, that we must look for the sources of the transformation.

LECTURE II

In the previous Lecture an attempt was made to give some indication of the lines upon which we are now advancing towards a solution of the sewage problem, and before going further it may be well to refer to certain developments which entail the necessity for collaboration between professions that have hitherto been regarded as having little in common. The advance of modern sanitation is now dependent upon the labours of not only the physician, the chemist, and the engineer, but within quite recent years of the bacteriologist as well.

The function of the physician is to discover and point out the relation between insanitary conditions and the diseases that they produce; that of the chemist is to investigate the nature of these conditions in the accurate terms of chemical analysis; that of the bacteriologist to deal with the life history and functions of the organisms that are now known to play the chief part in converting organic wastes into the harmless inorganic substances from which they were originally formed; and the work of the engineer is to give effect to these investigations in practical forms.

The relationships referred to are now becoming more and more intimate, each being dependent on the work of the other, and it is obvious that if the engineer is to take his proper share of the work he must possess sufficient knowledge of the subject of sanitation as a whole to enable him to perform his part with results commensurate with his responsibility.

Without going into the question of how much or how little the engineer ought to know of the special work of the other professions, it may be fairly said that it is only when a case is presented to him in a specific and practical form that he can be expected to do justice to the best method of dealing with it. Those conditions which can be dealt with by what are known as " Works " are universally admitted as coming within the department of the engineer, and they may be roughly classified under the following main objects of practical sanitation: 1st.—Selecting sites for new cities such as those which have sprung up in the irrigated deserts of India, or in new countries that are being developed under conditions of modern civilisation. 2nd.—Removing the organic wastes of men and animals so as to convey them from the neighbourhood of dwellings without creating a nuisance, and at a reasonable cost. 3rd.—Providing arrangements so that the interior of all dwellings should have immunity from the intrusion of offensive gases arising from the apparatus required for the removal of their sewage. 4th.—Revising methods for the purification of sewage so as to give effect to the latest discoveries and so as to avoid the pollution of lakes, water-courses and rivers, also without creating a nuisance, and at a reasonable cost.

It is too late to ask the advice of the engineer with regard to the situations of towns that are already built, and his work in this respect is limited to the cases already spoken of. Possibly the movement in the direction of Garden Cities may give him some employment, but the question of cost and convenience will, generally speaking, be the principal consideration in the choice of sites. The second department of sanitary engineering following upon the choice of a site is that which is concerned with the waste products of the inhabitants being conveyed to a distance from all dwellings, and, though the water-carriage system has now been adopted for better or worse as the only practical method of removal, it will be well to point out that there can never be one and only one way of dealing with the organic refuse from large and densely crowded communities.

So truly is this the case that one of the first objects of study should be the dividing lines which must always exist between one set of conditions and another, so as to avoid all enthusiasm for any particular method to the exclusion of others which may be far the best in some particular case.

The most casual acquaintance with the primitive methods still in use is sufficient to make this quite clear, even to those who have made no special study of the subject.

It could easily be shown that the methods now adopted in China and other Eastern countries could not be displaced by the most modern system without leading to a shrinkage in the food supply, which would involve half their inhabitants in starvation. One might go even further by showing that if the organic wastes in these countries were regarded as they are in England at the present time as a nuisance to be got rid of at any cost, and without a return of any kind, the entire population of whole provinces would have either to starve or to emigrate.

It has gone out of fashion to give this aspect of the sewage problem the slightest consideration, but such an attitude leaves altogether untouched the essential relationship which exists between population and the means of supporting it. Though we have adopted the obvious alternative of purchasing from other communities what we are unable to produce for ourselves, this is only possible in the case of rich nations who think they can afford to be wasteful, and have no thought for what may be in store for their descendants. Expectation of profit was one of the most inspiring elements in the evolution of sanitation, especially in relation to the disposal of sewage, and played a great part in the legislation of which we think so highly, but it must not be forgotten that while these hopes have been proved to be fallacious, it is now evident that if we had waited until profit had been proved before attempting to remedy the pressing evils arising from unsewered and filthy towns, we should have made hardly any progress at all. The fact still remains that the water-carriage system we have adopted is one that involves a gigantic waste of our potential food supplies, and no course of lectures dealing with the subject would be complete which failed to point out this element of failure in the plainest possible terms. While the ablest experts admit that the failure in this country has been absolute, and although many even go so far as to maintain that the search for a remedy is a waste of time, it does not follow that other countries can afford to be equally wasteful. From the modern standpoint of hygiene nothing could be more desirable than the sanitation of such a city as Florence by the latest methods of sewage disposal. This would involve the construction of sewers, the conveyance of the sewage by gravity or pumping to a suitable site at some distance from the city, and the introduction of the latest appliances for the purification of the discharge to a standard of purity at which it might pass into the river without polluting it. The effect of doing so would be to encroach upon the narrow margin of profit now obtained from the surrounding country to such an extent that cultivation would not support the labour to the margin of a living wage. At present the sewage is collected from cesspits and carried in variously constructed barrels upon carts to the neighbouring vineyards and olive yards. The labour involved in the carriage and distribution of the sewage may be taken as some measure of its value, and the loss entailed by the disappearance of the present system in the way suggested would be of such a critical kind that the contadini would no longer be able to make a living on the land.

In such cases it is obvious that the subject must be approached from the point of view demanded by the conditions as they actually exist, and since a limited water supply for the purposes of sanitation is an essential factor of the problem, which could not be modified without turning the scale against the profitable continuance of the present methods, it can easily be understood how complicated the problem may become when economic as well as sanitary conditions have to be complied with. Even in England it may be truly said that it is only the vast wealth of the community which makes the modern wasteful system of disposal possible, and the price we have to pay for our sanitation is sometimes in excess of anything that a poorer country could afford. There is no doubt that in many places abroad, where the inhabitants are imbued with habits of thrift, about which we in England know nothing and care less, any system of disposal must include a preservation of the manurial value of the sewage in order to comply with the elementary conditions of success.

This leads one to the conclusion that whether such a process as the one known as the A. B. C. system is the best or not, their argument about the necessity of preserving the value of the organic wastes for the land is altogether unanswerable, and must sooner or later assert itself.

If there is one more definite way of estimating intrinsic value than another, it must surely be found in the amount of willing labour bestowed upon any desired result in which the sole object is to obtain a saleable commodity. Judged by this standard, the price paid for sewage, in the expectation of a more or less adequate return, by the peasantry in the neighbourhood of Florence is truly surprising.

It must often amount to as much as 1s. 6d. per 100 gallons of sewage even at the low rate of wages prevailing in Italy, the cost being based upon one ton of sewage conveyed by mules to a distance of several miles from the town. Obviously the margin of profit must be encroached upon, or altogether disappear either by dilution of the sewage, a rise of wages, or an increase of distance, so that there, as everywhere else, the food supply of whole districts is dependent upon the balance between cost and return, while in Italy the margin must often be so narrow that it can only be adjusted by excessive hours of labour on the part of the contadini. In contrast with the above estimate of about 3s. per ton for the strong sewage of Florence, we have 2d. per ton as the value of diluted sewage in England, and this is regarded as negligible in practice. The land trouble in this country is essentially the same as in others, and it is now becoming acute because the balance of profit has disappeared and because the people are leaving the land. It may be truly said that the Chinaman has solved the economic problem of sewage disposal in so far as he has realised the "adjustment of the relations between the animal and vegetable kingdoms by which the vital functions of both are permanently maintained" more successfully than the Englishman, and although his methods may be altogether defective from the point of view of sanitation, yet enteric fever is unknown in many of his most densely populated provinces. The system of water carriage having now been almost universally accepted we are faced with the fact that the farmer is incapable of dealing with our sewage unless special provision is made for enabling him to do so. The failure of the sewage farm as a source of profit is now generally admitted, but the relations between the animal and vegetable kingdoms, so tersely referred to by Warington in 1850, must be adjusted before the sewage problem can be regarded as completely solved. In his presidential address to the British Association at Bristol, Sir William Crookes pointed out the necessity which exists for restoring the nitrogen of our sewage to the soil and estimated the loss arising from the wasted sewage of this country alone at £16,000,000 per annum. This sum would be sufficient to pay 3 per cent. on a capital expenditure of £350,000,000 and still provide £6,400,000 per annum for wages and depreciation. At present practically the whole of it goes to waste, and yet there are object-lessons available that prove what might be done with our sewage if its fertilising properties were available. It was shown in a paper contributed by Mr. W. E. Bear to the Journal of the Royal Agricultural Society in 1900, that under highly artificial conditions, grapes can be grown so as to produce an average of 12 tons to the acre, or 14 tons from vines in full bearing, and of tomatoes an average of 20 tons per acre, both crops to a great extent being grown upon the same acreage. Without the highly artificial conditions that produced these striking results potatoes can be produced in the open in this country so as to yield 20 tons per acre, and are sold for £5 per ton. In the face of such figures one can no longer be surprised at the sanguine views of those who looked upon sewage as a source of profit, and later on I shall refer to the possibility of recent processes to some extent being capable of realising their expectations.

In the previous Lecture it was pointed out that the water-carriage system was advocated and carried out in order to overcome definite sanitary evils in a definite and efficient way. There were, no doubt, many practical men at the time when the first reports recommended its adoption who must have had grave doubts about the possibility of utilising greatly diluted sewage upon heavy land, but the position taken up by the pioneers as set forth in the sentence quoted from Sir Robert Rawlinson was that something had to be done and done quickly in order to reduce a rapidly rising death rate. It must have been obvious from the first that, in districts provided with a slight natural fall to the point of discharge, the water supply must be ample in order to give a sufficient flow, and this necessity has no doubt contributed to raising the quantity of water consumed per head in all urban communities throughout the country. This in itself has proved to be expensive, and has led to the whole of England being now more or less mapped out for the water supply of our great towns. The belief in the value of sewage was quite genuine and its sincerity may be measured by the vast sums of money expended in giving, or rather in trying to give, effect to it, but the economic loss due to excessive dilution was never fully realised at the time. Here it should be noted that in the case of chemical treatment a strong sewage can just as easily have its solids deposited as a weak one, and as to the sludge there is little, if any, difference as regards the percentage of water contained in it, which in both cases averages from 80 per cent. to 90 per cent. Even with bacterial treatment it can be shown that with one sewage just double the strength of another both the hydrolytic and nitrifying fermentations simply become more active and give equally good results under identically the same treatment.

The difficulty of dealing with large volumes of diluted sewage is greatly added to in the numerous cases of storm water being conveyed in the same channels as the sewage to the outfalls of our great towns, and at the present time there are no really effective proposals for successfully dealing with the difficulty unless at a prohibitive cost. The provision of apparatus such as tanks and filter-beds to purify three to six times the dry-weather flow has been made one of the requirements of the Local Government Board, but even this is altogether inadequate in the case of a storm rainfall far exceeding this amount. Seeing that sudden changes in the volume of sewage passing through a filter-bed have the effect of destroying its efficiency for a considerable period after the flow has ceased, it appears as if the only satisfactory way of overcoming the difficulty is to retain the storm water in large reservoirs, constructed at the least possible expense, and, when the storm has passed, to treat their contents in works made large enough for the purpose so as gradually to deal with the weak sewage that has been accumulating during the period of excessive rainfall.

The other difficulty which has already been referred to is that arising from trade wastes being passed into the sewers. Sometimes these are of a kind that quite inhibit any bacterial action in the filters through which they pass, and in such cases there must be some radical means of dealing with them either by neutralising their effect or providing some other channel where a special outfall is provided for their treatment. Even where the manufacturing wastes consist of organic matter such as grease, the difficulty can only be met by the most elaborate precautions.

While still dealing with the second department which falls within the province of the engineer—namely, that of providing means for the removal of waste products of men and animals—it will be well to say something of the domestic aspect of the water-carriage system which has to do with the smaller details required for applying it successfully to the sewering of houses. With the most ample provision of a water supply a certain amount of economy is essential if the cost is to be kept within reasonable limits. With this end in view water companies and corporations who own their own works have been armed with the provision of bye-laws that are directed to the safeguarding of their interests from waste, and one of the first expedients to prevent this occurring was the compulsory use of waste-preventing cisterns, which only allow a limited discharge of water for each flush. The amount is frequently limited to 2 gallons, but this may be regarded as insufficient where the district in which they are fixed has a generally deficient fall between the highest part of the house drains and the invert of the sewers into which they discharge. In the case of London the flush used for closets in the low-lying districts referred to ought not to be less than 3 gallons.

Although the domestic details of water-carried sewage come within the humbler branches of engineering which are associated with the work of the plumber, it is impossible to exaggerate their importance, and there is no department of hygiene which has been carried to greater perfection in England than the work referred to. Just as few people realise the deplorable state of sanitation as regards public sewers in our great towns down to the passing of the Public Health Act of 1848, which has been spoken of in a previous Lecture, so it is equally difficult to realise the insanitary condition of the English home at a much more recent period. There seems to have been no very clear idea as to the relation which exists between the presence of foul gases and disease, in the mind of the average householder, until the tragic death of the lamented Prince Consort brought about a sense of its importance.

In a book, written by Pridgeon Teale, which did more than any other to arouse the attention of the community to the dangers to health arising from defective drainage, actual reproductions of the prevailing defects were shown in a popular form, and yet this treatise, one of the first of its kind, was only published in 1881, twenty-eight years ago.

The more well-to-do householders became alive to the importance of setting their homes in order in a sanitary sense, and since then a perception of the necessity for good home sanitation has pervaded the entire community. What was formerly left to the discretion of the individual owner and occupant has now become the subject of stringent bye-laws, which are almost universally in force. If the capital value of house property in London alone be taken at sixteen years' purchase of its rateable value, and the moderate estimate of 6 per cent. be taken as the average cost of putting the houses in the sanitary condition they are in at the present time, we arrive at the enormous figure of £36,000,000 as what must have been spent in hard cash by the inhabitants of London upon strictly domestic sanitation since the public was aroused to a sense of its importance about a quarter of a century ago.

When it came to be realised that there was a proved relationship between bad drainage and bad health, many minds went to work upon the discovery of how the dangers could be overcome, and the first epoch-making and master idea was that of making a complete disconnection between the house drain and the sewer. Hence came the development of the disconnecting trap, but before this occurred Dr. Fergus of Glasgow carried out the idea in a rudimentary but quite effective manner by means of a manhole with a half-channel pipe and running trap, which he constructed in his own back garden, and which I saw soon after it was completed about the year 1874. In 1881 the late Prof. Corfield showed me a manhole constructed upon similar lines, but with an improved form of trap, in his own house in Mayfair, and this was looked upon as quite a novelty in London at the time. The next step was to make sure that there were no defects in the house drains and the other sanitary details of the house itself, and we then find that there was a campaign of education carried out through the whole of England which was comparable to the work of Sir Edwin Chadwick and his colleagues in connection with the sewering and general sanitation of our towns. It was then that I was first impressed with the vast importance of this more humble branch of sanitation, and it is a great source of satisfaction to think that there is hardly a single detail of domestic sanitation to which I have not attempted to add an improvement of some sort.

It soon became evident that domestic sanitation is of the nature of a chain in so far that its weakest point is the measure of its strength, and that any faults of design or of workmanship, though apparently insignificant, might have results as fatal to health as if no attempts had been made to remedy the defects at all. This led to the demand for more conscientious work on the part of the workmen employed, and one of the leading characteristics of the movement took the direction of raising the status of the plumber to that of a skilled workman, to whose efficiency the community must to a great extent look for the preservation of its health. The result has been that England holds quite as prominent a position in the work of domestic as she does in that of public sanitation.

One notable feature of the reformation referred to was the constant increase that took place in the severity of the tests which were used to prove the efficiency of the workmanship, more especially with regard to the drains running beneath the basements of town and country houses.

In the case of the latter the endeavour was generally made to keep the drains outside of the house altogether, but as this was seldom possible with houses in a street, a great point was made of making the joints of drains absolutely tight. In order to prove their efficiency the first test took the form of passing smoke or pungent liquids into the drains in order to detect any leakage, but after a time this was considered inadequate, and it then became the fashion to test the drains with water. Considering the large number of joints required in a long length of stoneware drains, all of which had to be made under somewhat difficult conditions, the old happy-go-lucky way of laying them with unskilled labour became altogether impossible, and the greatest skill had to be used in constructing them in order to stand the test at all. It soon transpired that the stoneware drain, however good in itself, was not capable of standing the test of water with any degree of certainty over a long period of years, and as the slightest leak was held to be a sufficient reason for condemning them, it frequently happened that they had to be renewed every time the house changed hands, either in possession or in tenancy. Though it could hardly be maintained that a very slight leakage of sewage being absorbed by the earth at a depth of several feet below the level of a basement floor could be a danger to health, seeing that, if this were true, a well-manured garden might be looked upon as almost certain death, it was, nevertheless, considered necessary to condemn the drains as defective. This was an excellent system in so far as it was good for trade, but it was very hard on the citizen who wished to sell or to let his house. As the condemnation of house drains upon the discovery of the smallest defect worked most unfairly, and sometimes led to the same house being drained over and over again with each change of tenancy, it occurred to me to consider the suitability of cast iron as a substitute for stoneware, especially under the basements of houses when there was no possibility of keeping the drains outside. At the time this suggestion first appealed to me the late Sir Robert Rawlinson showed me specimens of cast-iron pipes that had been buried in the soil for many years, and having been protected by a solution invented by the late Dr. Angus Smith, were quite free from rust. Normal sewage is of such a greasy nature that it preserves the inside of iron pipes, so that the question of rust had only to be considered in so far as the pipes were attacked from the outside, and this could be provided against by laying them in cement. The advantages of cast iron as compared with stoneware in certain respects were obvious. The pipes could be laid in much longer lengths, with a corresponding reduction in the number of joints, and these could be made in the same way as water mains so that they could stand the test of a high pressure of water with the certainty of being tight.

Soon after having used cast iron for the drainage of several houses, I had an opportunity of adopting it on a large scale at the Foundling Hospital, where the old sewers were used as subways, a system of cast-iron drains being laid upon cast-iron chairs with provision for carrying away the drip water in half-channel pipes laid along the invert of the old sewers. It was a long time before the change to cast iron was generally accepted, but it is now almost universal, at any rate in London, and many local authorities have made it compulsory.

When the principle of disconnection had been applied to the outfall of the house drain before communicating with the public sewers it was evident that it was equally required in dealing with pipes that discharged into the house drains themselves, and it soon became the universal practice to disconnect the waste pipes of sinks, baths and lavatories so that they discharged openly into gullies that acted as traps. These were all constructed on improved lines, providing a permanent water seal, and the old bell trap which had come into general use was altogether abandoned. The combined system of disconnection and thoroughly efficient trapping soon became the cardinal principle of sound domestic sanitation, and with ample ventilation all the difficulties were overcome. When the work is properly done the results may be accepted as entirely satisfactory, and this branch of the art may be regarded as having reached finality.

Within the last few years discussions have arisen as to the necessity for having any trap at all between the house drain and the sewer. It has been argued that an excessive amount of carelessness is unavoidable in the cheaper kind of houses occupied by people who are altogether indifferent to what goes on with their drainage, and statistics have been gathered as to the number of cases in which the house drain has been made the vehicle for getting rid of materials such as scrubbing brushes, which could not be discharged through a trap of any kind. The other argument against the use of disconnecting traps has been that they interfere with the use of soil pipes with open ends as a legitimate means for ventilating the sewers, and that if the use of disconnecting traps were altogether abandoned there would be no more need for street gratings as the ventilation would take place through the soil pipes of the houses. The answer is that a well constructed house drain should never be in a condition to give rise to the existence of offensive gases of any kind, and that to admit those from the sewers is to abandon this element of safety in the house itself. It is true that the ventilation of sewers at the level of street gratings is not a sanitary arrangement, but because sewer ventilation still offers many difficulties it would be a mistake to interfere with the perfection which has been attained in our domestic sanitation by mixing it up with defects in the public sewers, with regard to which great efforts are now being made to find a remedy. In certain states of the atmosphere, and especially when the weather is calm, it would be a most risky system that provided for foul sewers being ventilated through the house drains where the gases would be absorbed and given out by the contents of all the traps, and still more to discharge the sewer gases on or about the level of the upper windows, where the great majority of the occupants are in the habit of sleeping. I have made special reference to these proposals because they have been urged by very ingenious arguments and in quarters that may carry considerable weight.

With regard to public sewers there is little to be said that cannot be found in the text-books that have been written on the subject for more than a quarter of a century. They certainly provide most successfully for all the requirements that inspired their early advocates to recommend their adoption as a means of getting rid of the great dangers to health arising from the accumulation of filth in the neighbourhood of dwellings.

About twenty-five years ago the late Sir Robert Rawlinson, when chief engineer to the Local Government Board, got out a model set of sewering plans that were intended as a help to municipal engineers and the engineering profession in general. They proved what marvellous progress had been made in a comparatively short time in bringing the art of public sewering to something nearly approaching perfection, and I do not know that they have ever been improved upon except in the matter of details, which are frequently more or less of the nature of a passing fashion.

Even at the time referred to the self-acting flushing syphon was coming into vogue, and taking it all round, those who have followed the designs of Sir Robert Rawlinson and Mr. Baldwin Latham have done quite as well as those who have departed from them.

The general principles that regulate the construction of sewers where gravity is available to give the necessary flow are exceedingly simple. They include the making use of the available fall to the best possible advantage, the construction of the sewers so that they are truly laid and not subject to any sagging or disturbance of any kind, and that they should have a cross-section which gives the smallest possible amount of wetted perimeter for every condition of flow.

This condition is met by an oval cross-section, which was first introduced by Mr. John Phillips in 1846. It was subsequently improved upon, the new form being stronger than the original and more self-cleansing with small volumes of sewage.

Sewers up to 18 in. diameter are best constructed in stoneware or concrete.

No lecture on the subject of sewering would be complete without some reference being made to the difficulties arising from an insufficient fall when the force of gravity is not available. We are indebted to the ingenuity and perseverance of Mr. Shone for a system which bears his name and which makes most efficient provision for discharging sewage to any required outfall by means of compressed air supplied from a central station and intermittently forcing the sewage from lower levels by means of ejectors. Tanks are erected underground at any desired and suitable points and so arranged that the sewage from limited areas discharges into them by gravity, and so that by means of automatic details as soon as an ejecting tank is filled the incoming sewage is cut off, and the compressed air being admitted by the opening of an inlet valve forces the sewage towards the outfall. Here there can be no provision for ventilation of sewers, and it should be noted that the conditions being mainly anaërobic the fermentation of the sewage may be carried to such a point as to make it unnecessary to have a separate provision for its liquefaction.

Where arrangements have been made by which only the sewage and the rain water from roofs and courtyards need be provided for, the sewers can of course be made of a much smaller capacity. When the soil is waterlogged it is often found difficult to avoid the intrusion of ground water with jointed stoneware pipes. In such cases it is advisable to use cast-iron pipes with lead joints as a substitute. It is sometimes by no means certain, however, that the passage of large quantities of subsoil water into old sewers is a disadvantage. The argument that where water comes in, sewage may get out, must be very much qualified by the state of the death rate in the district under discussion, and where this is a low one in a waterlogged town it may be looked upon as very probable that the leaky sewers have contributed to the result, and that if they were made tight and no elaborate system of water drainage introduced to take their place the outcome of the intended improvement might be an increase in the death rate directly due to its introduction. It must be remembered that the dilution required by the water-carriage system is so great that the manurial value of the liquid has been practically destroyed in any case, so that further dilution by underground leakage into sewers must be judged only by its effects upon the treatment it is proposed to apply to it. The sewage may be so diluted that there is no appreciable rise of temperature, or, in other words, almost no putrefaction with tanks in which active fermentation would occur with a stronger sewage. With very weak sewage the rate of flow through a bacterial percolating filter can be greatly increased and the size of the filtering material may be made much larger. In such cases a non-putrescible effluent can be obtained with little or no offensive smell, the filters do not clog, while the suspended matter coming away can be mechanically filtered so as to obtain a clear effluent.

These remarks are meant to show how necessary it is to approach each individual case strictly on its own merits, and with all the facts in evidence, before forming conclusions based upon data that at the best may have only a theoretical, and by no means a practical, bearing on some particular case.

Before leaving the subject of sewers it will be well to deal shortly with the question which is one of the unsolved problems still engaging the earnest attention of many engineers who have devoted much time and ingenuity to its solution. Sir Robert Rawlinson, who was a past-master in the construction of sewers, laid down the apparently very reasonable proposition that if they were laid with an adequate fall and were sufficiently flushed they would be self-cleansing, and that being so, their ventilation would be an easy matter if there were no foul gases to be dealt with. This seemed to be a solution of the problem by the simple expedient of avoiding the existence of the difficulty. I do not know if there are any sewers that meet the conditions he prescribed in which no nuisance has occurred, but it has transpired in ordinary practice that even sewers with ample falls and ample flushing still give rise to foul emanations from the street gratings. It has been shown that even with well-laid stoneware pipes and a fall in excess of what is required to make a sewer self-cleansing, which is taken to be a flow of not less than 3 ft. per second or about 2 miles an hour, and with thorough good flushing every week, complaints have arisen of offensive smells from the street gratings within twelve months of their construction. It must be observed that in practice the flow varies greatly at different hours of the day and night, and that this must involve the existence of large surfaces that are alternately covered by the rising and exposed by the falling flow. In house drains there can be no doubt that the fouled surfaces are a cause of smell even when there is an ample provision both of flushing and of ventilation. It has been shown that movement of the air in sewers is of the most erratic kind, due to the wind and other causes, and that arrangements that work admirably under certain conditions altogether fail owing to sudden changes which it is impossible to control. The mechanism required to prevent movements in an undesirable direction consists of non-return valves, but these require attention and renewal. The provision of ventilating shafts frequently gives rise to complaints that are fully justified by their unsatisfactory results.

It is difficult to obtain reliable data as to the immediate effect of existing arrangements on the public health, because the conditions overlap so as to make it a matter of doubt as to which may be accountable for different death rates, and it is not easy to determine what the conditions are that make one district more exposed to sewer emanations than another.

There is certainly no immunity on account of a rapid fall in a particular line of sewers, because the gases may find their way most freely to the highest level, and the escape from the street gratings may be as bad, or even worse, at the top than at the bottom of the incline.

As matters stand at present it really amounts to this, that a sewer open from end to end, or, in other words, a well-constructed ditch, is just as much or as little likely to be a source of disease as a sewer with its foul gases escaping in a more concentrated form at any particular spot.

It may be well to refer to certain health statistics obtained from a city unprovided with sewer ventilation of any kind. Mr. Steele, who was deputy city engineer to the Corporation of Bristol in 1903, contributed an important paper in which he stated that in Bristol "no means are intentionally made to provide a communication between the sewers and the atmosphere."

The city forms a basin, the general level of whose perimeter is about 240 ft. above ordnance datum, and whose centre is about 27 ft. above such datum, consequently the fall on the sewers is considerable.

All the street gullies are trapped, and since 1882 the drains connecting with the sewers have been provided with intercepting traps. On the building side of these traps communications are made with the atmosphere and another near the highest point of the drain. During the year ending December 31, 1901, over 4,800 systems were amended.

Taking diphtheria, fever, and diarrhœa as diseases in which sewer air plays any part, the death rate arising from them in Bristol compared with the average of thirty-three great towns was just one-half in the case of diphtheria, and little more than half with the other two. From all causes the Bristol death rate was higher than that of Croydon, Brighton and Portsmouth, equal to that of Leicester, and lower than all the others.

From diphtheria, the Bristol rate was higher than that of Bradford and Nottingham, but lower than all the others. From fever, the Bristol rate was higher than that of Croydon, but lower than all the others. From diarrhœa, the Bristol rate was higher than the Croydon rate, and lower than all the others. The infantile mortality in Bristol was higher than that of Croydon, but lower than all the others.

The author says that in so far as a trap fixed on the line of a drain affects the vital principle of its being self-cleansing, it may be regarded as objectionable, but that it is a necessary evil as applied to the drains at Bristol, and that no system of ventilation has as yet been found which could be tried in any district in the city without detriment to the others. He also asks the question, would the death rates of Bristol be reduced if special means were taken to ventilate the sewers, seeing that they compare favourably with those of other towns in which the sewers are ventilated? The responsible authorities in Bristol have quite an open mind on the question of sewer ventilation in general, but they hold the view that it has never been demonstrated that the practice at present applied in Bristol is prejudicial to the health of its inhabitants.

It has already been suggested that the existing defects in ventilation are the only weak points in what might otherwise be regarded as something nearly approaching to finality in the design and construction of domestic drainage and public sewers. The systems now being advocated come under the four headings of high-shaft ventilation, the cremation of the foul gases, chemical disinfection, and the hydro-mechanical system invented and introduced by Messrs. Shone & Ault. The last of these methods has the advantage of dealing with the ventilation of the house drains as well as the sewers by extracting the emanations from both by making the open soil pipes the inlets for fresh air and closing the openings from the street. Mr. Shone has kindly put a large diagram at my disposal which shows how the method is applied. The term hydro-mechanical has been used to indicate that the action of the water passing through the house drains is utilised to promote the free passage of air away from the house into the sewers, and the term mechanical refers to the work of electrically-driven fans fixed below the ground level at suitable intervals on the line of the sewers themselves.

The estimate of first cost per mile of sewer ventilated is given at £150, and the annual cost of the same at £30.

The system has been tried at Leicester under the superintendence of the surveyor, Mr. Mawbey, who reports that his fears about the unsealing of the seals of the house traps had not been realised, and that they had a steady flow of air away from eighty houses with a population of 356 persons; also that the carbonic-anhydride in the sewers had been uniformly reduced. I have made special reference to this system because it appears to be a satisfactory solution of the problem of sewer ventilation in a thoroughly practical way, and at a cost that is not unreasonable.

LECTURE III

In the previous Lecture it was pointed out that there is a necessity for collaboration between the physician, the chemist, the bacteriologist and the engineer, and I then went on to deal with the special work of the engineer in connection with the sewering of houses and streets. It was also shown that this department of sanitation, with the exception of difficulties that still exist in the efficient ventilation of sewers, had for practical purposes reached finality, and that the existing methods adequately serve all the objects for which they have been designed. Special reference was also made to the limitations of the water-carriage system, not as regards its success as a means of removing filth from the neighbourhood of dwellings, which was its original purpose, but because it has altogether failed as a means of restoring the waste products of our population to the fertilising of the land. We now come to the subject of sewage disposal, and this has two aspects which, although they have been separated to a great extent in practice, are nevertheless intimately associated, the one being the avoidance of pollution and the other the preservation of manurial value. It cannot be too clearly understood that in Nature the two are combined, and that when organic wastes have been reduced to their original inorganic elements the problems of purification and the preservation of manurial value have been solved simultaneously. Excessive dilution has added enormously to the difficulties of realising the combined solution.

Before dealing with the special subject of land it may be well to say a few words about the direct disposal of sewage into the sea or into rivers. The practice, except in so far as it provides a certain amount of food supply for fish, is not only wasteful but is destructive of fish life, when carried to excess. This arises from the action of the polluting matter in absorbing the available free oxygen in the water to a point below the requirements of all but the lowest forms of life which are associated with the putrefactive process itself.

Where great Continental rivers are available, and where the town populations are comparatively small, a process of self-purification goes on by which the polluting organic matter is completely oxidised, and the harm done is practically negligible a short distance below the points of discharge, always provided that the water is not used for drinking. The purification is due not only to the chemical changes occurring through oxidation, but from the mechanical effects of subsidence, in which the inorganic matter floating in a muddy river carries with it a great part of the organic matter in suspension to the river bed, where it is slowly converted by the action of bacteria into its inorganic elements. This self-cleansing process occurs on a vast scale in such rivers as the Rhone, and when a natural provision has been made by the intervention of such a lake as that of Geneva, and where a delta has been formed from a deposition of the matters in suspension, the water becomes so pure that it bears no resemblance to the same river where it is discoloured by alluvial mud. The effects of dilution and deposition also appear in a decrease in the number of organisms to be found at different parts of the stream. Above Lyons they have been found to be reduced to 75 per c.c., and below that city they are increased to 800 ; then again a process of reduction sets in, to be followed by similar changes until it reaches the sea. Even in America, however, where the rivers are of vast dimensions, the great increase in the town populations is beginning to encroach upon the purifying capacity of the stream, and in many cases disposal by dilution is becoming dangerous when the water is used for drinking. In England the rivers are not large enough to allow of any great quantity of sewage to be discharged into them with impunity. Where the water must be made potable, as in the case of the Thames, a large margin of safety is an absolute necessity, seeing that sewage effluents and the drainage from arable land have both to be purified. The difficulties of the problem are much the same in all countries, and have increased directly with the growth of great urban communities discharging their sewage into lakes and rivers.

Coming now to deal with the subject of treatment upon land as a means of sewage disposal and purification, the great sewage farm of Berlin may be taken as a prominent instance of success. It has an available area for irrigation of over 22,000 acres, and the most elaborate provision is made for carrying out the combined work of cultivation and purification under the strictest rules and regulations.

The whole of the land has been divided into plots of about 5 acres each, and arranged for the growing of different kinds of crops. Where rye grass or timothy grass is being grown the surface of the ground is carefully levelled to an average slope of about 1 in 30, and the sewage, having been brought to the top of the slope, is allowed to flow in a thin layer over the surface. These plots are ploughed up every fourth or fifth year, and before being used for broad irrigation the sewage is passed through roughing filters or tanks, as it has been found that the deposition of sludge on the surface of the land prevents the passage of air and eventually kills the plants.

A large part of the available area is laid out in ridge and furrow for the purpose of intermittent filtration, the ridges being 3 ft. wide and the furrows or ditches 18 in. apart. The sewage is allowed to flow in the furrows until they are nearly full, but so as not to overflow the tops of the ridges, and not to soil the crops that are grown upon them. It has been found that the tendency of the sewage is to take a lateral direction, as the solid matter collecting at the bottom impedes the vertical movement of the liquid.

The farm has been thoroughly drained on the parallel system, the average depth of the drains below the surface being about 3 ft. Mr. Roechling, who has made a study of the Berlin sewage farm and given much information with regard to its laying out and management, has supplied the following figures, which give some idea of the great scale upon which this farm is conducted: The total quantity of sewage treated is more than 30,000,000 gallons per day; the actual number of acres treated for each 1,000,000 gallons is 268; the persons to each acre actually treated are 156; the persons to each acre of farm 112; and the gallons of sewage per acre per day 2,687. Seeing that the work is chiefly carried out by convict labour it is difficult to make use of the figures of cost for comparison with other farms, and it should be noted that the land only cost at the rate of £40 per acre, whereas in England Dr. Barwise puts the limit of £150 as what may be regarded as reasonable, while in many cases it costs a great deal more.

The other great sewage farms on the Continent are those at Paris, Rheims, Breslau, Friburg, Dantzig, Madgeburg, and Odessa, but as stated by Dr. Calmette, the Chief of the Department now carrying on the work of sewage investigation in France, these great operations can only be carried out by the principal capitals or by smaller communities such as those named, where there are great tracts of land with sandy or chalky soils very absorbent and of little value. In another sentence he says, what may well be taken to heart in our own country, that in the case of towns of less importance, and less favourably situated, it is absolutely impossible to have recourse to this method of disposal at all.

Although nothing like on the same scale as the sewage farm at Berlin, an area of waste land has been dealt with by the Municipality of Paris at Gennevilliers, and more recently at Achères, extending to 4,000 acres, and all this, which was a barren waste, has been converted into fruitful gardens, and is available for the purification of the sewage from a population of 2,500,000 of inhabitants as well.

In contrast with the successful treatment by irrigation and intermittent filtration of sewage upon really suitable land, it may be well to take a case of typical failure in England, and it is sufficient to quote the Birmingham sewage farm to show how hopeless it is to expect satisfactory results from water-carried sewage even when a vast capital has been expended in attempting to obtain them from unsuitable land. The farm extends for about 6 miles in a narrow strip along both banks of the River Tame. Farm buildings, which may almost be spoken of as palatial, still stand as a record of the high hopes with which the scheme was inaugurated, and many trophies from the show-yards of agricultural societies prove what money can do even when business is conducted at a loss.

Every effort was made to put the land to the best possible use, but as time went on it became evident that successful farming was not consistent with the purification of the sewage, and the more it became necessary to rest the land in order to secure remunerative crops the less there was left for the purpose of purification. Things at last reached a point in which pressure was brought to bear upon the Corporation to abandon their dreams of profit, and the municipal farm has ceased to exist, seeing that the bulk of the land is let to farmers who are under no obligation to purify the sewage, but who are welcome to all they care to make use of. Even the soil that is well suited to the purposes of irrigation is not always available. Steam ploughs are frequently standing idle waiting for the weather to dry the land, which depends not only on an absence of rain but a certain amount of sunshine to make it fit for ploughing. It has been estimated that the average sewage farm in England is capable of dealing with the sewage from 200 persons per acre, but in the case of Birmingham, even with a total area of 2,830 acres, the rate would have to be 470 persons per acre if the whole of the sewage were dealt with.

This is greatly in excess of the requirements even on the successful sewage farms at Nottingham and Aldershot Camp, where per acre the populations are 397 and 166 respectively, and the gallons 23,300 and 25,000. These figures indeed are far beyond the capacity of the Birmingham farm to deal with, since it is estimated that the soil on the average is not capable of treating more than 10,000 gallons per acre all the year round. But it may be pointed out that the number of persons per acre is not a true basis upon which to make comparisons, seeing that there are great variations in the gallons of water used per head in different towns. The average of the water supply per head of the populations whose sewage is treated upon eight of the largest sewage farms is 40 gallons, which is a dilution that in the great majority of soils is another way of saying that the manurial value of the sewage has been completely lost. It would have been well indeed for the ratepayers of many of our great urban communities such as Birmingham if knowledge had preceded expenditure, and it seems to reflect little credit upon the free institutions of which we boast, that the law should have been allowed to run so far in advance of all reasonable means of complying with its requirements, as we now find in the somewhat painful object-lesson of an unsuccessful sewage farm. The misfortune is that legislation seems to go on with the momentum acquired during a period of sanguine expectations which have never been realised in practice, and that municipalities who are making every effort to comply with the law are being forced into extravagant expenditure which, on the admission of those best able to form a reliable opinion, will probably be wasted. The misfortune also is that opinions unfavourable to expenditure are seldom asked for and cannot be regarded as a very marketable commodity. To put matters plainly, an alteration of the law in the direction of reasonableness would encroach upon the interest of those who are directly concerned in its existing severity.

The extraordinary condition of things exists that an offending community is not even allowed to appeal to science in order to prove the impossibility of doing what the law demands, and frequently there is just that amount of success in evidence at one place to suggest that it will be quite certain in another under totally different conditions. The proposal now being made in certain high quarters, that a central rivers-authority should be formed who are to be their own court of appeal, sounds very like a change of masters, in which bricks are to be demanded before the straw has been provided for making them.

If the expenditure of money under the most skilled advice, as in the instance of the Birmingham sewage farm, did not lead to a satisfactory result either as regards profit or purification, it seems a reasonable conclusion that no success is to be looked for upon similar land in the case of smaller communities with more limited resources. In spite, however, of the evidence showing that successful sewage farming is necessarily limited to strictly confined conditions that are seldom available, the official attitude has persistently regarded land treatment as a method that ought to be abandoned only in exceptional cases.

Experience has shown that this should be reversed, and that it is only under exceptional circumstances that sewage farming can be adopted with the remotest chance of success.

Dealing with the subject of soils, Dr. Barwise has put it so clearly in his text-book, "The Purification of Sewage," that I cannot do better than quote from him as follows:—

"The soil should be of such porosity that it would absorb at the same rate that it would purify—that is to say, it should not be capable of absorbing more than 25,000 gallons per acre per diem, even if the sewage has the suspended matters first removed by means of precipitation.

"But, if the purification alone of sewage is aimed at and no return from crops is looked for, a much more open soil is most suitable; and if the sewage, after undergoing a rough form of precipitation, is only applied intermittently for a few hours, and the soil is given a rest for several days before any more is applied to it, a much larger quantity of sewage than this—indeed, as much as 100,000 gallons per diem per acre under special circumstances—can be purified.

"The danger with open soils is that more sewage will be applied than can be oxidised. What is generally taken by the average sewage farms as an indication not to apply more sewage is the fact that the soil begins to absorb less readily. It cannot be too emphatically stated that when this point is reached the land is overdosed. Provided, however, that too much sewage is not applied to the land, and it is applied intermittently, the more open the soil is the better, if it is a good thickness and the subsoil is fine gravel and uniform in texture. Even blown sand from the sea coast will thoroughly purify sewage if it is applied in small quantities at a time and the application is stopped before the sewage reaches half way to the land drains.

"It cannot be too clearly understood that there is no relation between the quantity of sewage that can be got to pass through the soil and the quantity of sewage that can be purified; for instance, a thin soil overlying a shaly open rock would take any amount of sewage, but will not purify more than a retentive clay." Dr. Barwise gives the following as some of the formations the soils of which are suitable for purifying sewage: "Alluvial drift and gravel, oolitic sandstone, bunter sandstone and the magnesian limestone when sufficiently weathered, the old red sandstone, and occasionally the millstone grit.

"The conditions under which irrigation alone should be adopted are where there is an open sandy loam or a loamy gravel which can be obtained at a price not much exceeding £150 per acre."

In practice it amounts to this, that where such circumstances are absent the treatment of water-borne sewage upon land can only meet with failure, or at most a very limited success.

Even under the most advantageous terms a sewage farm must be managed with the greatest care, and experience has shown that if the same acreage is to be used continuously without deterioration the sewage applied to it must be strictly limited to its capacity.

The Royal Commission on Sewage Disposal, in their fourth report, announced that they intended to publish reports by their experts upon the special subject of land treatment, and these appeared about nine months afterwards. They selected eight farms for detailed observation, but unfortunately that of Birmingham was not included in the list. They suggested the abandonment of the terms "intermittent downward filtration" and "broad irrigation," replacing them by the terms "land filtration" and "surface irrigation." Their reports are too lengthy to deal with in detail, but the following points were included among their general conclusions: (1) The results of land treatment of sewage from the bacterial standpoint are not fit to be discharged into drinking water streams. (2) Land effluents possess a bacterial flora which is more characteristic of sewage than of the soil. (3) The numbers of bacteria found in the sewage are much reduced in the effluents from land treatment. (4) There seems no reason to doubt that, with proper treatment, land can purify sewage for a practically indefinite period. (5) When discharged into non-polluted streams of relatively large volume, the land effluents did not prove injurious to fish. (6) Before sewage is applied to land it should be both screened and settled. (7) No direct or widespread injury to health has been proved to have been caused by a well-managed sewage farm. (8) Generally speaking, sewage farms can never be expected to yield a profit, but well-managed cropping aids purification. (9) On account of conflicting interests it is seldom advisable to let sewage farms. (10) Farm managers should have some special training, and the statistics of the farm should be most carefully kept. (11) The best crops are those that can be more or less continuously sewaged without injury. (12) During wet weather the normal working of a farm may be disturbed, and it is difficult to estimate the effects of storms upon sewage effluents. (13) Dilution can never be regarded as a proper substitute for purification. (14) "Resting" and "working" areas must be carefully alternated by the results of actual experience. (15) There should be a ratio of about 1 acre resting to 5 of working in the case of irrigated land, and 1 to 3 in the case of filtration areas. (16) The separate disposal of sewage does not justify the passing of other town drainage into streams without treatment. (17) The impossibility is recognised of treating the whole of the sewage during storms, and this affects the enforcement of drastic standards of purity. The Commission are of opinion that the imposition of hard and fast rules would not be to the interest of the public.

There is no doubt that the foregoing conclusions are justified by experience, but it may be observed that the official attitude in matters of this sort is characterised by a good deal of timidity, and in contrast to the cautious expressions of opinion contained in the reports we have the more direct statement of the Medical Officer of Health for Warwickshire, who said in his evidence that he considered sewage farms for the most part were doomed. It seems strange that an important point in connection with the treatment of sewage upon land has apparently escaped the notice of the Commission and is not referred to in the reports of their officers. It ought to have been stated that in the practical management of sewage farms it frequently happens that when all the conditions *should* be favourable there is a falling off in the quality of the effluent that cannot be accounted for, and this is frequently due to the burrowing of rats, moles, and worms, which provide a direct passage for the sewage from the surface to the drains, without purification. Deep ploughing, in so far as it may obliterate the passages to a certain depth, may provide a partial remedy, but shallow ploughing only makes it more difficult to trace them, and it is obvious that, where the effluents discharge into rivers used for drinking, the defects may become just as serious a danger to health as dry-weather cracks in clay soils or fissures in the chalk.

It was one of the recommendations contained in the reports to the Commission that sewage before being treated upon land should be strained and settled. This brings us to the subject of preliminary treatment. If it is advisable to protect the surface of irrigated land and filtration areas from the clogging by solid matters, which soon renders them more or less impervious and interferes with the aëration of the soil, it is equally necessary to do the same with artificial filters. Even if their washing were an inexpensive process, which it is not, the loss of capacity in the body of the filters is only exchanged for the loss by their being put out of use while cleansing. Although it may be true that in the case of some sewages the putrefactive fermentation can be brought to a point of activity sufficient to hydrolyse even the grosser organic matters in suspension, it by no means follows that this extent of putrefaction would be the best *as a preliminary to nitrification* in a trickling filter, and the more so as it has been shown that a strong sewage when subjected to excessive putrefactive changes becomes refractory to nitrifying changes of any kind. One or two witnesses who gave evidence before the Royal Commission objected to screening of the sewage altogether, but when it is remembered that these grosser matters, which in the case of the Barking outfall amounted in 1895 to about 90 tons per week, have been carried without great expense, along with the sewage, to a point far removed from dwellings, it would seem that they at any rate might be dealt with in such a way as to make them of some value as manure. If they were mixed with a sufficient quantity of earth to render them inodorous, and after being passed through a pug mill were allowed to nitrify under open sheds, the amount of manurial substances contained in them ought to meet with a ready sale.

In addition to screening it is necessary to make provision for a mechanical deposition of the inorganic matters in suspension, and this is done in detritus tanks. They should always be arranged in duplicate to allow of one being cleaned while the other is in use. The mineral matters can either be separated by the action of gravity, which requires quiescence obtained from a slow rate of flow, or by making use of a rapid flow in a chamber shaped so as to occasion a rotary movement by which they are thrown out centrifugally and deposited upon a sloping surface. The amount of the product reaches on an average about 10 parts per 100,000 in addition to the organic matter which they are not meant to deal with. There is no reason why this organic matter, when one detritus tank is out of use, should not be washed forward with septic effluent so as to leave only the mineral matter behind, and itself to undergo more active fermentation in the hydrolysing tanks from which the septic effluent has been drawn.

Coming now to the subject of chemical precipitation, it has already been explained that in no case can this be properly regarded as anything but a preliminary process, because experience has shown that there is no chemical treatment capable of producing a non-putrescible effluent at a reasonable cost. The advocates of the A. B. C. method of treatment, to which reference has already been made, claim that they can obtain a clear effluent devoid of smell, but the weight of evidence goes to show that it has not the stability eventuating from treatment in a good bacterial filter. For this reason chemical deposition should be looked upon as strictly confined to the work of separating the matters in suspension and equalising the quality of the effluent, which is an important element in the successful working of bacteria beds. Before these were introduced it was the organic matters in solution that were the most difficult to deal with, and the experts of twenty years ago looked upon any process that added to them as distinctly a step in the wrong direction. This is now regarded as one of the principal objects of anaërobic fermentation, and much evidence was brought before the Royal Commission as to the comparative advantages of chemical treatment and hydrolytic fermentation. Certainly the latter is the less expensive, seeing that the work is done by changes that occur spontaneously, but there are cases in which the septic process is so offensive that chemical treatment may be required to expedite the deposition and so reduce the nuisance.

I do not know if, among the great number of methods that have been proposed for the chemical treatment of sewage, any of them attempted to produce changes similar to those that are now obtained from the bacterial action that takes place in tanks and filters, but it was soon discovered in practice that the action of chemicals was best confined to their capacity for precipitating the organic matters in suspension in the form of sludge, and the chief object was to have as much of the suspended matter separated from the sewage as possible. A great part of this work was done by mechanical clarification due to subsidence. It was found that after straining about one-half of the carbonaceous matter and one-third of the organic nitrogen in sewage remains in suspension. The late Sir Edward Frankland, in his evidence before the Royal Commission on Sewage Disposal, went further, and stated "what appeared to the eye to be offensive in sewage is the substance in suspension; but it is the organic matter in solution which chiefly contributes to the pollution of rivers. There is about one-seventh part of polluting matter in sewage in suspension, and the remaining six-sevenths are in solution." The discrepancy between these two estimates, the first of which is given by Dr. Rideal, shows how difficult it is to make a general statement applicable to all kinds of raw sewage; but, whatever the proportion may be, it was found that simple deposition aided by clay or other suitable materials did not give satisfactory results, seeing that active putrefactive fermentation kept up a constant movement in the liquid and interfered with the process of settlement.

Reference has already been made to the early introduction of lime as a precipitant soon after its application to the softening of water, and it has been shown that the best results are obtained when the lime is applied in solution. When used in conjunction with other precipitants the results are more satisfactory, both by reducing the amount of matters in solution and as regards the general quality of the effluent; but, like all other chemical processes, it is defective in so far as there is an inherent tendency to further putrefactive changes in the clarified sewage. The introduction of bacterial processes to take the place of chemicals, by allowing time for the organic matters in suspension to precipitate in large tanks, was found to have the same defect as deposition aided by clay, inasmuch as the fermentation led to a constant disturbance of the suspended matters. It was then claimed that this action itself was an advantage, and that after a scum had formed on the surface there was a constant movement kept up, which resulted in a complete liquefaction of all the organic matters in suspension, so that nothing was left in the tank but an inoffensive residuum that only required to be removed at long intervals. It was maintained by the advocates of this process that by septic action alone all the polluting matters might be accounted for, partly by their disappearance in gaseous forms and the rest as being thrown into solution. It was then presumed that further purification in a contact bed would in all cases give satisfactory results. Experience has proved that these expectations could not be realised in practice, and it was shown that except in the case of very weak sewage the question of the putrefactive fermentation had many complications, and that if it was allowed to establish itself in the contact beds the whole of the process ended in failure.

As time went on it was proved that better results could be obtained from the arrangement of upward filtration through flints or stones than in empty tanks, because in this way colonies of liquefying organisms could be maintained that gave the putrefactive fermentation a more definite character. But with either arrangement it has now been definitely accepted—(1) that what is known as single contact treatment does not give anything like such good results as that to be obtained from percolating filters; (2) that double contact is at the best only an attempt to realise the same results in a more uncertain way, and that any carelessness may give rise to septic action in the contact beds, and so bring the whole process to the position of an offensive failure. As between chemical treatment, however, and bacterial liquefaction, regarded as preliminary processes for the removal of organic matters in suspension and the production of sludge, all the available evidence goes to show that in the case of ordinary sewage there is not much to choose between them, except that the latter is much less expensive.

Chemical processes can be carried further than being employed simply as a means of precipitating solids in suspension that have come over from detritus tanks, and when used as a means for the production of dried and saleable sludge have an important bearing upon the economical aspect of the sewage problem. There can be no doubt that the low prices obtained for agricultural produce in this country, owing to their free import from regions more favourably situated, must materially affect the prices that farmers can afford to pay for the raising of crops at home, but it should not be difficult to arrive at the prices which would create a demand for sewage fertilisers so as to turn the scale and lead to our municipalities making efforts to supply it at a profit. As matters now stand, the balance is against making the attempt, but it is of interest to know that the present estimated value of dried sludge is by no means negligible. The average value taken from twelve towns is stated by Prof. Robinson to be about 17s. 6d. per ton, and although some prejudices might have to be overcome, if it paid the farmer to purchase it and the municipalities to produce it, there is every reason to suppose that both the demand and the supply would be forthcoming. It should be observed, however, that the Native Guano Company, who have stood out bravely for the commercial value of sewage, and the estimated value of whose products head the list above referred to, charge a great deal more than the theoretical value given in the estimates, and yet require a considerable subsidy from the municipalities who have adopted their system.

Before leaving the subject of the possibility of obtaining from chemically-treated sewage a saleable manure that can be produced so as to yield a profit, it should be remembered that it does not in the least matter how much money is spent upon the production of food so long as there is an adequate return. The case of potatoes grown in the open country so as to yield 20 tons to the acre at the price of £5 per ton could never have been realised unless at great expense for the purchase of manure and much labour upon the land, but there must have been a handsome profit all the same. From the point of view of employment, the more labour that is employed the better, so long as there is an adequate return, and the most costly methods are economically sound if they comply with this condition.

It will be well now to deal shortly with the extraordinary incoherence which exists in the practice of different towns in regard to the preliminary processes we have been describing.

It might have been expected as the result of so many years' experience that some common standard would have been reached so that the reasons for adopting one system in preference to another could have been quite easily explained and understood. So far, this has seldom or never been regarded as of any importance, and the question of one system being preferred to others is often decided without a reference to a scientific basis of any kind. The case of the two great cities of Glasgow and Birmingham are a good illustration of the incoherent position of the whole subject both in theory and practice. The system that has been adopted in Glasgow is chemical precipitation, yet, at the very time this was being decided on, Birmingham, after many years' experience, deliberately abandoned it, and have had no reason whatever for regretting their decision. The first financial result of the change so far as Birmingham is concerned was a saving of £5,000 per annum for the purchase of lime, and all the machinery and buildings connected with chemical treatment of the sewage have been swept away as completely as if they had never existed. It seems quite certain that if the Birmingham experts had been acting for Glasgow the treatment by chemicals would have never come into existence at all, and *vice versâ*, if the Glasgow experts had been advising Birmingham they would have been going on spending more and more upon lime, which was the advice given to them by a distinguished chemist, whose suggestion they have ignored, with the large annual saving above referred to.

In these two cases all the experts could not possibly have been right, because one of them has been proved to be wrong, but the only way of accounting for the difference of the two systems now actually at work at the two places on any rational grounds is that what was good for one sewage did not apply to the other, and this is the crux of the whole question. It is surely obvious that there can be no satisfactory answer unless both systems can be subjected to measurement by a common standard in exact and intelligible terms. In speaking of this incoherence in the practice of sewage treatment, on another occasion I referred to the case of much smaller towns than Glasgow or Birmingham, and took the instance of what has occurred with an Urban District Council in the Home Counties as typical of what is being done all over the country. The local surveyor gets out plans and an engineer from Westminster is called in consultation.

He suggests modifications, and proposes a scheme that he believes will give good results ; but in doing so he recommends that only half of the work should be carried out to begin with, and that the other half should be completed when experience has been gained from the working of the first.

No doubt the engineer exercised commendable caution when giving this advice, but what would have been thought of him if he proposed only to build one-half of a bridge, and that the other half should not be finished until he found that the first half did not fall to pieces? Would this not be on the face of it an admission of incompetence? Yet, to be on all fours with the advice given about the sewage of this particular town, the analogy would have to be carried still further, and ignorance of the reasons for success in the case of his bridge built in two halves would have to be admitted if it were to be compared with his sewage scheme, in which the most important factors remain unmeasured and practically unknown when his sewage works are finished. Another case in point exists in the experience of a town in Staffordshire, where excellent results were obtained upon data obtained elsewhere that happened to apply, but where it was not discovered until the works had been long completed that the filter-beds had been made nearly double the depth that was necessary, involving a waste of money that ran into several thousand pounds. In contrast to this systematic ignoring of any kind of accuracy based upon measured data, there is the case of the town of Staines that obtained the required information beforehand, and carried out works corresponding to the experimental data to within a margin of 10 per cent., which came out on the right side.

Before leaving this branch of the subject, which is obviously of the greatest importance, one may well ask the question how it is that the rival merits of such contradictory methods as contact beds and trickling filters should ever have been a matter for serious discussion at all. In any other science that is worth the name, data must have been available to test the claims of the two methods by conclusive experiments that would have given a final and definite answer. This, of course, presupposes the existence of some common standard of measurement, which in every scientific investigation is regarded as essential to progress of any kind. The very fact of the contact system (presuming it to be less efficient than percolation through well-aërated filters) having survived so long proclaims the absence of any standard means of comparison, and inversely if contact is better, then the existence of a standard would have confirmed the fact. The truth is, however, the two systems are so widely different that any means of comparison by a common standard would be practically impossible, and it therefore is right to inquire into the genesis of the contact bed in order to discover how it ever came to be proposed at all. What takes place in a contact bed has been investigated by chemists and bacteriologists at the expense of much time and labour, but there is no evidence that it was deliberately adopted to begin with upon anything but the off-chance of its success, following on the discovery that the even distribution of great volumes of liquid over large surfaces was a much more difficult problem to solve than was at first supposed. No satisfactory means of distribution being available, the filling and emptying of a tank containing burnt ballast was tried as an alternative without preliminary data of any kind. This is all fully admitted by the late Mr. Santo Crimp in his evidence before the Royal Commission, and it is almost incredible that vast sums of public money should have been spent upon methods which had no support except in the results obtained from the Massachusetts experimental filters, which embodied totally different features. It has now been discovered that a great part of the purification obtained from contact beds is due to the tendency of organic matters in solution to be absorbed by gelatinous growths which are promoted by the conditions and which remain in the body of the material, so that the purification results have been all along most misleading. What Dr. Rideal condemns as "combined liquefaction and nitration, indiscriminately in the same receptacles," is so utterly at variance with the factors that were known to be necessary for high nitrification, that one can only wonder how chemists and bacteriologists could ever have given their countenance to contact beds as being a serious contribution to the solution of the sewage problem, and still less, even to the suggestion that vast sums of money should be spent upon their application to the purification of the sewage from densely populated towns before investigating more rational methods.

In the light, or one ought rather to say in the obscurity, of such methods of dealing with the sewage problem, it need not be a subject for surprise that bacterial processes should have been carried on in a haphazard way, and unless the whole subject is put upon a more scientific footing no satisfactory progress can be made.

In the next Lecture some attempt will be made to show how matters can be improved by the simple method of making sure that the conditions necessary to success are ascertained before spending money in ignorance of what they really are.

LECTURE IV

If the question were asked as to how much an engineer, engaged in the work of sewage disposal, should know of chemistry and bacteriology, I suppose the answer would be the more the better. Yet it is unreasonable to expect that he should be an expert in either subject.

What is really wanted is that the chemist should know a great deal about that side of bacteriology which deals with the chemical changes that are due to the action of micro-organisms and their products, and that he should present his requirements in a way that the engineer can understand.

One of the witnesses who was examined before the Royal Commission on Sewage Disposal, and who was an engineer, had to state certain results that were obtained from a particular apparatus, and in doing so simply quoted from the analyses which had been supplied by a chemist. The figures, in the light of the existing knowledge of the time, appeared to be contradictory, seeing that there was a simultaneous increase in two of them which seemed impossible, because as one rose the other should have fallen. Now, although the difficulty referred to has been cleared up in the light of further investigation, it was hardly for the engineer to attempt an explanation, and had he done so it would have carried little weight unless it had been a very obvious one. In this case the engineer was responsible for the apparatus that produced the results, and the chemist responsible for their analysis. The question may well be asked as to whether or not this is the proper relationship that should exist between them. Hitherto it has been the engineer who has produced the apparatus, and the chemist has seldom come forward with practical proposals of any kind. It seems more reasonable that the chemist should have been the one to point out how any desired result could be obtained, and that he should have presented the facts in such a way that the engineer could comprehend what was wanted. As matters stand, it really amounts to this—either that the chemist must be an engineer or that the engineer should be a chemist, combining both in his own person. The chemist has hitherto failed to urge the absolute necessity for the work of sewage purification being conducted under clearly defined conditions. He knows that certain reactions can only be produced by quite specific means, but instead of insisting upon their provision, he has simply looked on while the engineers have been doing as best they could, and he has analysed their results. In such circumstances there is little wonder that no progress has been made upon lines that can be regarded as satisfactory. At the present time there is not a single proposition which meets with universal acceptance. The law has gone far beyond any generally accepted means of complying with its requirements, and vast sums of money have been and are still being spent upon schemes differing so widely in kind that they cannot all by any possibility be right. With regard to methods that are certainly wrong, I have already referred to the quite misleading interpretation that has been put upon the analyses of the effluents from contact beds. As Dr. Rideal states: "It is obvious that if the non-nitrogenous matter is arrested by the filter-bed, the improvement in the effluent, as measured by the oxygen consumed figure, must in part be attributed to this cause, at the expense of clogging or diminution of capacity."

Seven years ago I said that "it is unfortunate that while the experiments at Barking and Exeter did more than any others to advertise the process of bacterial purification and bring it into general notice, they at the same time have retarded the solution of the problem by failing to follow it on the only lines upon which a final solution is possible."

If the chemists had only put their requirements in a specific form and stated in exact terms what is required for the purification of any particular sewage, the task of the engineer would have been a comparatively easy one. If they could report beforehand that the best results could only be obtained by subjecting a certain sewage to a definite number of hours in a hydrolysing tank, it would be a simple matter to arrive at the proper dimensions for any rate of flow. If they could state beforehand the number of gallons of air per gallon of sewage that is required to produce a given standard of nitrification, and the depth of filter and periods of rest needed in each particular case, the work of the engineer would be confined to designing the necessary apparatus, and his position would at least be intelligible, whether he succeeded or not.

Under existing conditions it is obviously right that engineers, without becoming experts either as chemists or bacteriologists, should have some clear conceptions as to the nature of the work that can be accomplished by the micro-organisms that are not only Nature's scavengers, but the agents for restoring organic wastes to the production of food.

Dealing with the phenomena actually involved, it may be well to make an attempt to put them in a popular form.

It is a familiar experience to find mathematicians such experts in the use of symbols and formulæ that the layman is unable to follow their reasonings or to understand the process by which they have reached their conclusions. In the same way the work of the chemist frequently fails to be of any service to the engineer unless it is conveyed in the shape of definite suggestions. The details of the new science of biolysis are quite inexhaustible, and it cannot be expected that the engineer should be able to select those that are essential and disregard those that have only a subsidiary importance. The composition of food is sufficiently complicated, but when it has been subjected to the process of digestion it is still more difficult to investigate. What we must always bear in mind is that it has originally been built up by the life processes of plants and animals, and that the forces we invoke in the bacterial purification of sewage are due to the work of micro-organisms, whose great function it is to reduce organic substances to their original inorganic materials. It has been discovered that Nature is capable of performing the necessary transformations under the most simple physical conditions, and that the work is completed to such perfection, when these are fully provided for, that ordinary domestic sewage with a strength measured by a chlorine content of 7 parts per 100,000 can be made as pure from the point of view of the stability of the foreign matters contained in it as the water from the Thames taken from above the intakes of the Metropolitan Water Board.

Taking albumin as one of the principal substances to be dealt with, its approximate percentage composition consists of 54 parts carbon, 7 parts hydrogen, 22 parts oxygen, 16 parts nitrogen, and 1 part of sulphur. When phosphorus, potassium, calcium, sodium and chlorine are added to the list it includes nearly all the mineral substances from which the organic polluting matters in sewage were originally built up. If it were necessary to provide separate means for dealing with each of these substances in their organic state, the difficulties would be altogether insurmountable; but it has been found in practice that the organic nitrogen, in the great majority of cases, is the only constituent that involves any special study, and the others are seldom even estimated, with the exception of the chlorine, which is used as an index of the strength of different sewages. So far as the engineer is concerned, if he produces an apparatus capable of mineralising 80 per cent. of the organic nitrogen he has solved the problem, always provided that he does so without creating a nuisance, and at a reasonable cost, and it should be noted that when he has succeeded in this he has solved the problem in a double sense, because he has produced an almost perfect plant food as well. It appears, therefore, that Nature, even with the apparently fatal effects of excessive dilution, which makes the use of raw sewage upon all but exceptionally suitable land a failure, has provided a valuable result when used under highly artificial conditions.

Referring now more particularly to the organic nitrogen, which is the basis of most of the difficulties in disposal, I think that the chemists have hitherto failed to present the problem of its oxidation in a light that is intelligible to a layman, or even to themselves, judging from their own divergent views about the exact meaning of one of the stages to which they have given the name of albuminoid ammonia. It is far beyond my capacity to suggest any improvement, but at the same time it is necessary to form some sort of conception of what takes place in order to arrive at practical conclusions, and I am on safe ground when I confine myself to a statement which does not conflict with any of their own observations.

Speaking, then, in popular terms, the organic nitrogen may be looked upon as existing in different states, some of which are more resistant than others to the changes that depend upon chemical combination with oxygen.

Any liquid polluted by the presence of organic nitrogen compounds, whether actively putrescent or not, may be regarded as in a transition state in the presence of bacteria or their ferments, but it is apparently impossible to differentiate the changes as they occur, except by methods of analysis from which results can be obtained showing the quantitative amount of organic nitrogen that has reached the transition stage (1) of free ammonia, and (2) the undefined and more refractory stage known as albuminoid ammonia.

It must be remembered, however, that these estimations do not in any case represent the total nitrogen either in the original liquid or in any stage of its purification, but that in sewage there is invariably a still more refractory form than the one which is spoken of as albuminoid, and that this breaks down to the albuminoid or some allied transition state before the final oxidation to nitrates. It can be understood, then, how complicated the subject becomes when an unfortunate engineer is first educated to believe that the albuminoid ammonia is the standard he must comply with, and afterwards discovers that his filters, instead of reducing it to the required extent, are actively breaking down the still more refractory nitrogen to the very stage he is trying to eliminate. He may console himself with the knowledge in such cases that his filters are doing excellent work, and that if they are sufficiently aërated the nitrates in the effluent will be an ample set off against the other apparently unfavourable conditions. In other words, it is now becoming generally admitted that if the ratio between the oxidised and the unoxidised nitrogen in the effluents is adequate all the other transitions can take care of themselves.

The other estimate which is universally given in sewage analyses is the "oxygen-consumed" test. This is more intelligible than those just referred to, and may be spoken of as the measure of those substances that have not reached such a stability as to have no further avidity for oxygen.

Another estimate which is almost universally made is that of nitrites and nitrates, and I think, from an engineer's point of view, this is by far the most important of any. One has only to refer to such a paper as that which was read by Dr. Dunbar, of Hamburg, before the Sanitary Congress at Glasgow in 1904, to see how much the chemists are in disagreement as to any methods of analysis that are of universal application. The fact of the matter is, that the changes occurring during the process of biolysis are so complicated that it is quite impossible to interpret them in terms of any chemical analysis, except roughly and for practical purposes, simply because the estimations cannot possibly have the refinement that is fully explanatory of the constantly-changing composition. The superiority of the nitrates as a test of efficiency arises from the fact that they represent the ultimate standard of stability with regard to the unoxidised nitrogen which "is a constituent of the more dangerous kinds of natural pollution, and that the proportion between the oxidised and unoxidised nitrogen denotes the extent to which the sample has been purified" (Rideal). It may be taken as certain that when the engineer has developed a process which gives a ratio of 96·7 per cent. between the oxidised and unoxidised nitrogen, as in the case of the Ashtead experiments, all the other elements are negligible from a practical standpoint. It should also be observed that while the oxidised nitrogen, in combination with a suitable base such as exists in most sewage in the form of lime or soda, has reached the final stage of oxidation, the oxygen of the nitrates is still available by denitrification as an active agent for bringing the unoxidised residuals to a further stage in the direction of final mineralisation.

In the concluding paragraph of Dr. Rideal's chapter on chemical analysis in the third edition of his text-book, "Sewage and Sewage Purification," he makes the most significant observation that "the percentages of purification given in some statements only indicate the work done by the sewage installation, but not necessarily the quality of the effluent," whereas in every case the ratio of the oxidised to the unoxidised nitrogen taken in connection with the chlorine content, when this is a fair measure of its strength, is an absolute test of the effluent's stability.

The next estimate, that of chlorine, has already been spoken of as a useful measure of the strength of normal sewage, seeing that it remains constant itself (unless dilution occurs), while other matters are changing or being removed. It gives no detail indication of the *nature* of the sewage, but in practice it has been found that in the absence of trade refuse it is a fair means of comparing the relative quantities of organic matter in different sewages. In a recent experiment, to which I shall afterwards refer in more detail, it was found that by halving a water supply the chlorine was almost exactly doubled, and it is in this sense that the estimate is of value.

Before leaving this part of the subject it will be well to say a few words on the subject of nuisance arising from offensive odours. The anomaly exists that the nuisance spoken of has no necessary relation to the quantity of polluting matter that gives rise to it. Atmospheric conditions, and, above all, temperature, are important elements in its production, and an amount of organic matter that appears almost negligible in a volumetric analysis, when inoculated with a suitable organism may give rise to an intolerable stench. The difficulty of deodorising in such cases does not arise from the small quantity of deodorant that is required to deal with the immediate odour, but from the fact that the other organic matters absorb the reagent to an extent that makes its application prohibitive on account of cost.

The same objection applies to the use of disinfectants that are used up by the substances that do not require to be transformed.

If it is difficult for an engineer to express in popular language the chemical phenomena accompanying the bacterial purification of sewage, it is even less easy for him to do the same with the bacterial side of the problem, and I can only ask your indulgence when making the attempt.

There are two terms, aërobic and anaërobic, which are in constant use, for which we are indebted to the illuminating genius of Pasteur. They represent the dividing line between two kinds of micro-organisms—*viz.*, those that can and those that cannot live without air—but it is a line that is frequently crossed. Without going into details, it is sufficient to observe that whether or not a particular aërobic organism can work under anaërobic environment, or *vice versâ* in the case of those that are anaërobic, the difference between results achieved by the two classes is of the most remarkable kind.

The anaërobic changes come under the general term of putrefaction, and the aërobic of oxidation, but they are both biolytic, and, in their separate activity, they both break down organic substances into simpler molecular forms.

It has been questioned whether the anaërobic *must* precede the aërobic action, and the equally important question is, *ought* the one to precede the other, whether it is absolutely necessary or not? The only provisional answer that I know of is that, in the case of the highest results that have ever been obtained in the bacterial purification of sewage, the one did precede the other as a matter of fact. About the great difference that exists between the two processes there cannot be any doubt, seeing that one produces gases that can be used as illuminants and the other those that will put out the light of a candle. The question of previous anaërobic treatment from a practical standpoint must be judged from the effect it has upon the work of the organisms engaged in carrying the oxidising changes to the point of required stability. On this aspect of the case it may be found that the highest results can be attained by sterilising the liquid before it is passed through a well-matured oxidising filter.

It is of the greatest importance to have definite information about the best period at which to utilise the effects of anaërobic fermentation with any particular sewage, and it is obviously necessary that some appliance should be provided for the purpose of obtaining estimations, in terms of accurate measurements, of the arrangements that give any required result. The need has already been recognised by La Caisse Nationale des Recherches Scientifiques in France, who have adopted a standard apparatus, but there is no sign of any but rule-of-thumb methods having any chance of adoption in England, and at present there is nothing in the text-books which rests upon a commonly-accepted basis of any kind as regards the anaërobic treatment of sewage.

The knowledge that is quite indispensable in order to design bacteria plant for the purification of sewage is as follows:—

1st.—It is necessary to know the best period during which the anaërobic or putrefactive fermentation should be carried on. It is upon this information alone that the proper dimensions of the tanks for the hydrolysis of any particular sewage can be stated with confidence, and ignorance of this factor makes the dimensions of the tanks a mere matter of guesswork.

2nd.—The quantity of air must be known which is required, when favourable bacterial conditions are present, to oxidise the organic substances which have been rendered unstable by the anaërobic fermentation, or, in other words, to take full advantage of the life-processes of the organisms which are available.

3rd.—When the proper period of anaërobic fermentation and the proper quantity of air have been ascertained, it is necessary to know the proper depth of filter, because, as in the case of the hydrolysing tanks, ignorance is productive of nothing but speculation. It may often happen that twice the necessary amount of filter depth has been used because of an inadequate air supply.

4th.—The discharge must be made intermittently and the quantity that the filter is capable of dealing with ought to be known beforehand, and never exceeded.

5th.—The proper period of rest between each discharge should be known in order to insure that the bacteria should completely dispose of one amount before they are called upon to deal with another.

It does not follow that the best period necessary for hydrolysing the organic polluting matters in a particular sewage is coincident with the best period at which it should be discharged upon the filter, from the point of view of being most susceptible to final oxidation, and it is therefore advisable to find out by actual experiment the period that gives the best mean result.

Dealing with the air supply, it should be observed that this can be met at a small outlay by quite available means which are now completely disregarded. To nitrify 5 parts per 100,000 of organic nitrogen in an effluent (1 gramme in 20 litres), about half its volume of air is used up in the process. This is the quantity required to produce the necessary reaction, but it by no means represents the quantity that should be passed through the filter, because carbonic acid is formed in large quantities, and should be either removed or greatly diluted with air so as not to interfere with the work of the organisms.

If the foregoing information is essential in order to insure the success of large installations, it surely follows that those who are responsible for the spending of public money upon sewage works should long ago have taken steps to insure that it is not being wasted upon undertakings in which the requisite knowledge has been conspicuous by its absence.

There are other important questions that have to be decided before an engineer is justified in committing his clients to large expenditure.

One of these is the best size of material for the filters. All things being equal, there is every reason to believe that small material graded to particles of about one-quarter to one-eighth of an inch will give the best results, but not with sewage which contains brewery refuse or other substances having a tendency to produce gelatinous growths that soon fill the interstices. The matter is again one that can only be decided by actual experiment beforehand, and with suitable apparatus a short time is all that is required to discover whether the size of the material is suitable or not.

Presuming now that the engineer has all the necessary data at his disposal, and that he has obtained from a testing apparatus a sample complying with the required standard of purification which it is his business to reproduce upon a large scale; he can then proceed to get out plans and prepare for the equipment of a single unit of the proposed works. This is flying in the face of one of the requirements of the Local Government Board, who demand as a prelude to their approval that the ratepayers should be forced into a complete scheme often based upon inadequate data. As there is not much likelihood of the responsible department making any change in this stipulation, the only course that is open to a local authority is to put down a unit without going to the Local Government Board to give their sanction to a loan. One would have thought that a department which has been instituted for the express purpose of safeguarding the ratepayer's money would have been the first to accept the trial of a unit beforehand, because it would then be on safe ground and in a position to give its sanction upon the basis of the actual results arrived at in each particular case. The day may come when matters are regarded in a reasonable light, but meanwhile it will be well to say something of what the engineer must bear in mind in the event of his having it in his power to proceed with a free hand. First of all he must remember that, as all the conditions in the testing apparatus were made as uniform as possible, it is necessary that the same rule should apply on the large scale if he is to obtain corresponding results.

The sewage under observation should be allowed to pass on to the testing filter day and night with the same constantly-changing conditions as those that will occur with the full-sized installation, and as the rate in both cases should be uniform, provision must be made to give effect to this very important factor. This can be done on the large scale by means of a module such as that which is used for irrigation, or in the form devised by Mr. Martin which works with a difference of level of about an inch. The apparatus consists of a module-chamber having a circular opening at the bottom; through this opening is a body, conoidal in shape, attached to a float. As the head of liquid in the chamber falls so does the float and cone, making the opening larger and correspondingly making the orifice smaller when it rises. It should be noted that even in cases of heavy rainfalls, the bacteria beds that produce a high nitrification in the effluents will perform a more efficient duty in supplying available oxygen to less purified effluents from storm-water reservoirs, than in having their efficiency diminished by irregular and excessive use.

When we have ascertained the rate of flow that gives any desired standard of purity from a known depth of filter, with the periods of rest between each discharge which have been proved to give the best results, the next step is to make sure the liquid is distributed over the surface of the filter-bed with extreme accuracy. The importance of this element of regularity arises from the loss due to portions of a filter being underdosed, and so being partly unused, while other portions, being overworked, are subject to the risk of becoming inefficient owing to the establishment of undesirable organisms that it may be very difficult to eradicate.

This question of accuracy has been largely disregarded on the score of expense, but it is to be observed that the best results can only be obtained from really accurate distribution. The majority of the distributors on the market are rotary and self-acting, but as the power available from the hydraulic head that is generally available is very small, the frictional resistance must be reduced to a minimum, and this precludes their being supported by running on a rail fixed on the coping of the circular wall of the bacteria bed. As a consequence, the cheaper kinds are arranged with double arms revolving round the centre and suspended by stays from a central post or pillar. An inherent objection to these devices is that the stays are subject to contraction and expansion due to variations in temperature, and this is very difficult to eliminate or counteract. The sagging of one of the long arms of this class of distributor by even the small fraction of an inch makes a serious change in the rate of discharge from its extremities. It may generally be taken that a more substantial structure supported upon rails at its periphery will give much better results. One point of importance with regard to distribution is that, as all the different factors should be under control and capable of adjustment, it is difficult to understand how this can be attained by any automatic device in which one or more of the factors is fixed by the requirements of the machine. It may generally be taken that unless in the case of small installations, where the expense would be relatively heavy, it is best to have the distributing apparatus driven by a prime mover that is capable of easy adjustment. It has been found that the rate of flow required to give standard results should be regulated at different times of the year, and the same applies to the periods between each discharge. At Staines it was found that a period of about seven minutes gave the standard under normal conditions in summer, but that fifteen minutes were required to deal with the heavy discharge from the October brewings that formed part of the sewage. In the case of rectangular filter-beds a different type of apparatus is required, and there is a drawing in the first edition of Dr. Rideal's book, p. 255, which has been adopted at Hanley, and which gives excellent results. In the case of rotary distributors it is necessary to make provision for the varying areas covered by the revolving arms. This is best arrived at by the device of a continuous duct discharging into another running parallel to it, but divided into sections, so that each receives a quantity of liquid corresponding to the area to be covered.

This principle has been embodied in a rotary distributor at Hanley, and also at Birmingham, with excellent results, but in both cases the apparatus has been made unnecessarily heavy.

The question of cost has so far been the chief consideration in the choice of distributors, and has led to the adoption of spraying nozzles in some of the largest installations. The efficiency of these appliances as regards accuracy of distribution has been most elaborately investigated by the experts of the Massachusetts Institute of Technology, and the results of their experiments appear in a paper contributed to the *Technology Quarterly Magazine* of March, 1907. This monograph is fully illustrated, and represents a painstaking investigation of the most exhaustive kind. I think it is most unfortunate that any sort of support should have ever been given by persons responsible for the public health to any kind of sewage distribution that involves the spraying of pathogenic organisms, especially when no provision is made to provide against the action of high winds in throwing them broadcast into the atmosphere. No fewer than twenty varieties of streptococci have been found in London sewage, and these are described as being "the most pathogenic of all bacteria at present known." It is universally admitted that when conducive circumstances are present the danger arising from the presence of pathogenic organisms is extreme. I have no hesitation in saying that spraying septic sewage will one day be the cause of an alarming epidemic outbreak, and that after many lives have been lost this system of distribution will be absolutely prohibited.

I must now go on to deal with a most important feature of the bacterial treatment of sewage which has come a good deal to the front, and is a quite legitimate subject of discussion. I refer to the retention of the organic polluting matters in the body of the filter.

Reference has already been made to the misleading effect of analyses from contact beds in which there is no estimation of the purification due to retention. In the case of a strong brewery sewage I have found that the substitution of a top layer about one foot in depth of fine material in place of gravel graded to about ¾ in. had the effect of giving rise to gelatinous growths which quite upset the working of the filter and were not got rid of either by resting or washing. If this result had been arrived at in the early days of the inquiry it might have led to the definite abandonment of the system, which shows how unreasonable it is to draw conclusions from any particular case unless they are strictly confined to its own conditions. Arguments drawn from installations that do not provide the necessary features of success may be regarded as part of the literature of failure, and this has already reached quite remarkable dimensions. The question of the residual substances that are not capable of dissolution is only of importance in so far as they implicate the successful application of bacterial processes when all the requirements are complied with. It is true that even with the best working there are residual substances that are not subject to anything but slow disintegration because "they are very stable and resist chemical action," but, on the other hand, it should be remembered that this stability is one of the principal objects of the entire process itself. When they are produced from the anaërobic stage it has been found that they are inoffensive if they have been retained in a secondary tank only emptied at long intervals of time.

When they are the products of the aërobic stage obtained from well aërated filters, whether or not they are partly formed from matters in solution that have become colloid, they are so flocculent that they come away quite readily from the surfaces of the filtering material, and this should never be made finer than will allow of their passage. They seriously affect the appearance of effluents when in suspension, but are readily deposited in tanks which may conveniently be formed in the bottoms of the filters themselves, as has been done by Mr. Hall at Staines, where they are removed every morning and separately treated. Looking at the position broadly as it now stands, one cannot but be struck with the fact that there are only two cases I know of, where a sample has been produced beforehand of an effluent obtained from accurately measured conditions, and which have been produced upon a large scale. Yet surely this is a most reasonable preliminary to demand in every case. Why should an authority charged with the responsibility of spending the money of the ratepayers to the best advantage not request an engineer who has got out a scheme to show his confidence in its efficiency by actually obtaining beforehand a specimen of what his proposed apparatus will produce if this can be done at a small expense? He ought to know that the anaërobic fermentation should be of the right duration, then why should this be a question of guesswork? Why should he make out plans showing filters 5, 9 or 12 feet in depth, without being sure that 3 ft. is not all that is required to give the satisfactory results? Should the question of air supply be left to take care of itself, when he knows that it is an essential factor that *must* be provided for? The peculiarities of any particular sewage are so completely beyond the power of any chemist to estimate in terms of what is required to purify it, from a bare analysis, that he too is bound to make use of an apparatus for measuring the conditions that will give a required result. In looking through the literature of the subject one finds a great mass of information gathered from hundreds of experiments, and in every case there are numerous differences in the details, many of which are not measured in any way. In all experiments the point to be aimed at is that all the physical factors are identical in kind with easy adjustments for the purpose of comparison in accurate terms.

In the fourth volume of contributions from the Sanitary Research Laboratory of the Massachusetts Institute of Technology, there are most interesting records of experiments recently made with the Boston sewage after treatment in hydrolysing tanks and trickling filters. As was to be expected, a number of the results require most careful study in order to arrive at a comprehension of the complicated processes, both chemical and bacteriological, which go on during the process of anaërobic fermentation, but the results with regard to the matters retained in the tanks are quite positive and of the greatest interest.

During the twenty-one months of the investigation, 21,490,000 gallons of sewage passed through the septic system. This volume of sewage carried 2,790 lb. of suspended solids (of which 1,880 lb. were volatile) and 188 lb. of organic nitrogen. The septic system therefore removed 1,120 lb. of solid matter (580 lb. volatile and 540 lb. fixed) and 54 lb. of organic nitrogen. There were left, stored in the tanks, after twenty-one months of operation and one month's rest, 675 lb. of solids (of which 109 lb. were volatile) and 8 lb. of organic nitrogen. Four hundred and seventy-one pounds of volatile solids and 46 lb. of organic nitrogen had, therefore, been decomposed in the tanks, while the fixed solids had been increased by 26 lb.

On the whole, it appears that the septic tank will remove nearly two-thirds of the fixed suspended solids from the

Boston sewage and about one-third of the organic matter, as measured by suspended volatile solids or organic nitrogen. Of the organic matter in the sludge thus removed four-fifths is decomposed. The fixed solids, on the other hand, accumulate to such an extent as to require the cleaning of the tanks once in two or three years. A seven-hour period gives as good an effluent as a twelve-hour one, and probably produces a less accumulation of sludge.

An equally elaborate series of experiments was made with trickling filters having a total area of 200 square feet divided into two equal areas, from both of which samples were taken simultaneously. The distribution was by means of gravitation sprinklers consisting of concave discs upon which the effluent from the septic tanks splashed from vertical pipes placed immediately above them. The depth of the filters was 8 ft., but why this depth was chosen is not stated. The analyses from these filters are quite extraordinary, and the figures suggest that a recrudescence of micro-organic life must have occurred, probably about the fifth foot of depth, completely reversing the process of mineralisation which had been going on in the upper layers of the filter. The whole arrangement of the filters was not of a kind that is likely to be adopted as a standard, and it is unfortunate that there were no samples taken at intervals of a foot in order to discover the progressive changes as they occurred. The bacteriological examination of the effluents also suggests the recrudescence referred to, seeing that at Caterham, with a very much stronger sewage, the organisms were reduced from 2,180,000 per c.c. to 50,000 or 98·5 per cent., while in the Boston experiments the septic effluent contained 1,650,000, and the effluent from the filters 750,000.

Quite recently a case occurred in which it was necessary to provide for the treatment of the sewage from a small-pox hospital in accordance with the variation in the number of patients from zero to one hundred. Anaërobic tanks for the caretaker and his family were obviously insufficient for ten times the number, and a provision for the maximum number would have been excessive. This led to the installation being arranged in units so that they could be used as needed, but since no information was at hand as to what the units should be, the committee arranged that a series of experiments should be made in order to arrive at the necessary data. It was also required to find out if a filter 3 ft. thick, which was all the depth available, was enough to give the proper standard of purity in the effluent. One unit was constructed on the supposition that a period of twenty-two hours in the tanks would give the best results. As the hospital was in the course of erection there was an opportunity of basing the experiments upon a known composition of sewage, and this was obtained from the fæcal and urinary discharge from ten workmen with a small amount of soap from two lavatory basins which might be regarded as negligible. The contents of the tanks and the water supply were accurately measured, so that a time-estimate could be gained of the periods during which the putrefactive fermentation took effect. By altering the capacity of the tank and taking the samples at suitable hours, any required changes could be made upon the periods of hydrolysis, and arrangements were also effected for taking samples of raw sewage. The chlorine was used as a guide to the strength of the sewage, and proved quite satisfactory, seeing that doubling the strength of the sewage by halving the water supply gave approximately twice the chlorine content.

The testing apparatus employed was identical in all respects with that which is being used by La Caisse Nationale des Recherches Scientifiques in France. The flow was arranged at the rate of 1,000,000 gallons per acre per twenty-four hours during the whole of the experiments, and the period of seven-and-a-half minutes was fixed for every rate of flow between each discharge of liquid upon the surface of the filter. Provision was also made for taking samples from the second, third and fourth foot of filter depth. The anaërobic cultivation tank was started on the 23rd of September, 1907, and the filter on the 4th of December following. The first samples were taken and the analyses begun on the 22nd of January, 1908.

The trials were of great interest in more than one respect, seeing that the drains were new, and that all the results were obtained from the organisms of the alimentary canal and their enzymes without any others than those that might possibly have found their way from the atmosphere.

Seven series of samples were taken at intervals between each sufficiently long to admit of the tank and filter settling down to the altered conditions as they arose. The filtering material was made up of three grades of saggers, each 4 in. in depth for the top foot, the sizes varying from one-eighth to a quarter of an inch with local gravel graded to about 1 in. beneath. The results were quite satisfactory, insomuch that it was possible to hand to the committee an actual sample of what they might expect at all states of occupation up to 100, and at the same time they threw a new light upon the capacity of a well-matured filter, working under good management, to purify sewage under much varied circumstances. The periods of hydrolysis were altered from twenty-two to forty-seven, to nine, and to four hours, and to none at all in the form of raw sewage, and yet in every case the effluents were non-putrescible and chemically satisfactory. The question of air supply was not gone into, because the installation was too small to admit of mechanical aëration being available. The filter was of a total depth of 6 ft. and open at the bottom. When the strength of the sewage was doubled, as in the case of the forty-seven hours' hydrolysis, the effluent was still good, the free ammonia in parts per 100,000 being 1, the albuminoid ammonia 1, the oxygen consumed 0·48, and the nitrate 1·4 at the third foot of filter depth, the chlorine content being 8·0.

The experiments prove the immense importance of extreme regularity in the methods of using a filter.

In conclusion, I think that those of you who have read the literature of the subject cannot fail to have observed the extraordinary anomalies that exist with regard to it. On the one hand, it must have seemed impossible, even a few years ago, to believe that it would be anything but folly to expect that the polluting matter in the sewage of a great city, amounting to many thousands of tons, could by any chance be disposed of by microscopic creatures so small that 20,000 of them would only measure the length of a single inch. It is only when one begins to recognise their amazing capacity for reproduction that their functions appear to be equal to the vast task of converting the entire waste products, not only of men and animals, but of all things, animal and vegetable, that have ever possessed life, to the original inorganic elements from which they had been raised by the alchemy of living.

Again, when we think of what actually must occur in this vast and universal transformation, we recognise the existence of processes so rapid and so complicated, that they go far beyond the range of our finite intelligence ever fully to explore or to understand.

When we realise this, we may well wonder at the fact that, so far as the disposal of sewage is concerned, the work of these creatures can be carried out, to something nearly approaching finality, by means of a tank and a heap of cinders.

It has been this amazing element of apparent simplicity which has been most misleading, and has led many workers to ignore the necessary conditions under which Nature is prepared to become the obedient and the ever-active servant of man. If I have been able to contribute ever such a humble quota to the solution of the problem, upon the lines demanded by Nature before she is willing to perform a service of any kind, I shall have had some recompense for the almost constant work which I have given to originating and developing the science of biolysis for the last seventeen years. Finally, I must say how deeply I appreciate the honour of having been selected by the Senate of the University of London to deliver the first course of lectures under the benefaction of Sir Edwin Chadwick, whose distinguished work as a sanitarian has placed him among the immortal benefactors of humanity.

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